

AWS D1.4/D1.4M:2018
An American National Standard



Structural Welding Code— Steel Reinforcing Bars



AWS D1.4/D1.4M:2018
An American National Standard

Approved by the
American National Standards Institute
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Structural Welding Code—Steel Reinforcing Bars

8th Edition

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Prepared by the
American Welding Society (AWS) D1 Committee on Structural Welding

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This code covers the requirements for welding steel reinforcing bars in most reinforced concrete applications. It contains a body of rules for the regulations of welding steel reinforcing bars and provides suitable acceptance criteria for such welds.



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Foreword

This foreword is not part of this standard but is included for informational purposes only.

In 1961, the American Welding Society published its first reinforcing steel welding standard, AWS D12.1-61, *Recommended Practices for Welding Reinforcing Steel, Metal Inserts and Connections in Reinforced Concrete Construction*. The D12 Committee was disbanded some time after publication of the 1961 code and before publication of the 1975 edition.

The 1961 document was replaced with a greatly revised version, AWS D12.1-75, *Reinforcing Steel Welding Code*, with the format patterned after the AWS D1.1-72, *Structural Welding Code*. The 1975 code was produced by the AWS Structural Welding Committee but was not renumbered to reflect this committee change. As with ANSI/AWS D1.1, AWS D12.1-75 was designed as a self-contained code, including within it the qualification of welders and procedures, and requirements for workmanship, quality, and inspection.

The listings of materials and welding processes were revised in the D12.1-75 code. Items newly introduced were the carbon equivalent method for determining preheat, the parenthetical inclusion of metric (SI) conversions, and the two different methods of joint strength determination.

The AWS D12.1-75 document was revised and the title changed to ANSI/AWS D1.4-79, *Structural Welding Code—Reinforcing Steel*. Since the 1979 edition of ANSI/AWS D1.4, *Structural Welding Code—Reinforcing Steel*, was issued, further use by designers, engineers, and fabricators has necessitated a number of changes to the requirements; the 1992, 1998, 2005, and 2011 editions reflected these changes.

The evolution of AWS D1.4/D1.4M, *Structural Welding Code—Steel Reinforcing Bars*, is shown below:

AWS D12.1-61	<i>Recommended Practices for Welding Reinforcing Steel, Metal Inserts and Connections in Reinforced Concrete Construction;</i>
AWS D12.1-75	<i>Reinforcing Steel Welding Code;</i>
ANSI/AWS D1.4-79	<i>Structural Welding Code—Reinforcing Steel;</i>
ANSI/AWS D1.4-92	<i>Structural Welding Code—Reinforcing Steel;</i>
ANSI/AWS D1.4-98	<i>Structural Welding Code—Reinforcing Steel;</i>
AWS D1.4/D1.4M:2005	<i>Structural Welding Code—Reinforcing Steel;</i>
AWS D1.4/D1.4M:2011	<i>Structural Welding Code—Reinforcing Steel; and</i>
AWS D1.4/D1.4M:2018	<i>Structural Welding Code—Steel Reinforcing Bars.</i>

Changes in Code Requirements. Underlined text in the subclauses, tables, or figures indicates an editorial or technical change from the 2011 edition. A vertical line in the margin indicates a revision from the 2011 edition.

Summary of Changes

Clause/Table/ Figure/Annex	Modification
Clause 1	Restructured to identify new safety and health information; new materials added. GTAW is now permitted as a prequalified welding process.
Clause 2	New clause that lists all normative references. This replaces subclause 1.9 from the 2011 edition.
Clause 3	New clause that provides terms and definitions specific to this standard. It replaces subclause 1.5 from the 2011 edition.
Clause 4	Previously Clause 2 in the 2011 edition. Base metal stresses and allowable stresses in welds were removed and replaced with new content on the design of welded joints. New Table 4.1 covers design strength and the allowable strength of welded joints.
Clause 5	Previously Clause 3 in the 2011 edition. New content on lap joints: bar diameter range, effects of eccentricity, and lap joints in an anchorage. Figures 5.1 through 5.5 modified for clarification.
Clause 6	Previously Clause 4 in the 2011 edition. New content on foreign materials and coatings, weld size. Figures 6.1 revised for clarity. Figure 6.2 extensively revised to include new schedules for weld profiles.
Clause 7	Previously Clause 5 in the 2011 edition. New content on GTAW electrodes and filler metals. Tables 7.1 revised to include several A5 filler metal specifications, most notably AWS A5.36.
Clause 8	Previously Clause 6 in the 2011 edition. Table 8.2 revised to include GTAW, bar diameter groups, and AWS A5.36. Figure 8.5 revised for clarity. Figure 8.8 is new.
Clause 9	Previously Clause 7 in the 2011 edition. Radiographic methodology shall now conform to ASTM E94.
Annex A	Sample forms now include GTAW.
Commentary	Commentary is new for this edition. This is a practice used by other D1 codes and as such will now be included as part of this standard.

Informative Annexes. These annexes are not code requirements but are provided to clarify code provisions by showing examples, providing information, or suggesting alternative good practices.

Errata. It is the Structural Welding Committee's Policy that all errata should be made available to users of this code. Therefore, any significant errata will be published in the Society News Section of the *Welding Journal* and posted on the AWS web site at: <http://www.aws.org/technical/d1/>.

Suggestions. Your comments for improving AWS D1.4/D1.4M:2018, *Structural Welding Code—Steel Reinforcing Bars* are welcome. Submit comments to the Managing Director, Standards Development, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166; telephone (305) 443-9353; fax (305) 443-5951; e-mail info@aws.org; or via the AWS web site <<http://www.aws.org>>.

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Structural Welding Code—Steel Reinforcing Bars

1. General Requirements

1.1 Scope

This code shall apply to the welding of the following:

- (1) Steel reinforcing bar to steel reinforcing bar, and
- (2) Steel reinforcing bar to carbon or low-alloy structural steel.

When this code is stipulated in contract documents, conformance with all provisions shall be required, except for those provisions that the Engineer or contract documents specifically modifies or exempts.

1.2 Units of Measurement

This standard makes use of both the U.S. Customary Units and the International System of Units (SI); the latter are shown within brackets ([]) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

1.3 Safety

Safety and health issues and concerns are beyond the scope of this standard; some safety and health information provided, but such issues are not fully addressed herein.

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by the materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies:

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

1.4 Application

1.4.1 General Requirements. This code shall be used in conjunction with the prescribed general building code requirements and is applicable to all welding of steel reinforcing bars, using the processes listed in 1.6, and performed as a part of reinforced concrete construction or in the manufacture of precast concrete components.

1.4.2 Impact Properties. The weldments specified in this code shall not be used where impact properties are a requirement of the general specification. Impact testing requirements of welded steel reinforcing bars are not included in this code.

1.4.3 Engineering Approval. All references to the need for approval shall be interpreted to mean approval by the Engineer.

1.5 Steel Reinforcing Bar Base Metal

1.5.1 Materials. Steel reinforcing bar base metal in this code shall conform to the requirements of the latest edition of one of the ASTM specifications listed within this paragraph. Combinations of any of these steel reinforcing bar base metals, when welded, shall use a welding procedure specification (WPS) qualified in conformance with Clause 8:

- (1) ASTM A615/A615M
- (2) ASTM A706/A706M
- (3) ASTM A767/A767M: zinc-coated (galvanized) steel reinforcing bars that meet the requirements of ASTM A615/A615M or ASTM A706/A706M
- (4) ASTM A775/A775M: epoxy-coated steel reinforcing bars that meet the requirements of ASTM A615/A615M or ASTM A706/A706M
- (5) ASTM A934/A934M: epoxy-coated prefabricated steel reinforcing bars that meet the requirements of ASTM A615/A615M or ASTM A706/A706M
- (6) ASTM A1055/A1055M: zinc and epoxy dual-coated steel reinforcing bars that meet the requirements of ASTM A615/A615M or ASTM A706/A706M
- (7) ASTM A1094/A1094M: galvanized steel reinforcing bars that meet the requirements of ASTM A615/A615M or ASTM A706/A706M

1.5.2 Unknown Composition. When a steel reinforcing bar not listed in 1.5.1 is approved under the provisions of the general building code or by the Engineer, its chemical composition and carbon equivalent shall be provided and welding procedure shall be qualified in accordance with the requirements of 8.2 and all other requirements prescribed by the Engineer.

1.5.3 Approved Base Metals. Base metals, other than those listed in 1.5.1, shall be one of the structural steels listed in the latest edition of AWS D1.1, *Structural Welding Code—Steel*, or any steel stipulated in the contract documents and the welding procedure shall be qualified in accordance with the requirements of 8.2 and all other requirements prescribed by the Engineer.

1.5.4 Carbon Equivalency. In order to determine minimum preheat requirements as defined in Table 7.2, the carbon equivalent of steel reinforcing bars shall be calculated as shown in 1.5.4.1 or 1.5.4.2, as applicable.

1.5.4.1 ASTM A706/A706M Carbon Equivalency Exception. For all steel reinforcing bars, except those designated as ASTM A706/A706M, the carbon equivalent shall be calculated using the chemical composition, as shown in the material test report, by the following formula:

$$C.E. = \%C + \%Mn/6 \quad (Eq. 1)$$

1.5.4.2 ASTM A706/A706M Carbon Equivalency. For steel reinforcing bars designated ASTM A706/A706M, the carbon equivalent shall be calculated using the chemical composition, as shown in the material test report, by the following formula:

$$C.E. = \%C + \%Mn/6 + \%Cu/40 + \%Ni/20 + \%Cr/10 - \%Mo/50 - \%V/10 \quad (Eq. 2)$$

1.5.4.3 Unavailable Material Test Reports. If material test reports are not available, chemical analysis to determine C.E. value may be made on bars representative of the bars to be welded.

1.5.4.4 Preheat for Unknown Material Composition. If the chemical composition is not known or obtained:

- (1) For bar size number 6 [19] or less, use a minimum preheat of 300°F [150°C].
- (2) For bar size number 7 [22] or larger, use a minimum preheat of 500°F [260°C].
- (3) For all ASTM A706/A706M bar size numbers, use Table 7.2 C.E. values of “over 0.45% to 0.55% inclusive.”

1.6 Welding Processes

1.6.1 Welding Processes. Welding shall be performed with shielded metal arc welding (SMAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), or flux cored arc welding (FCAW).

1.6.2 Other Welding Processes. Other welding processes may be used when approved by the Engineer, provided that any special qualification test requirements not addressed by this code are met to ensure that welds satisfactory for the intended application will be obtained.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard in use at the date of the contract bid submission shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

American Welding Society (AWS) standards:

AWS A2.4:2007, Standard Symbols for Welding, Brazing, and Nondestructive Examination;

AWS A3.0M/A3.0, Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying;

AWS A5.1/A5.1M, Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding;

AWS A5.5/A5.5M, Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding;

AWS A5.12M/A5.12 (ISO 6848:2004 MOD), Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting;

AWS A5.18/A5.18M, Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding;

AWS A5.20/A5.20M, Specification for Carbon Steel Electrodes for Flux Cored Arc Welding;

AWS A5.28/A5.28M, Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding;

AWS A5.29/A5.29M, Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding;

AWS A5.32M/A5.32 (ISO 14175:2008 MOD), Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes;

AWS A5.36/A5.36M, Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding;

AWS C4.1, Criteria for Describing Oxygen-Cut Surfaces;

AWS D1.1/D1.1M, Structural Welding Code—Steel; and

AWS QC1, Standard for AWS Certification of Welding Inspectors.

American National Standards Institute (ANSI) standard:

ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes

American Society of Civil Engineers (ASCE) standard:

ASCE/SEI 7, Minimum Design Loads for Buildings and Other Structures

American Society of Mechanical Engineers (ASME) standard:

ASME Boiler and Pressure Vessel Code, Section V, Article 2

American Society for Nondestructive Testing (ASNT) standard:

ASNT Recommended Practice No. SNT-TC-1A, Personnel Qualification and Certification in Nondestructive Testing

ASTM International standards:

ASTM A615/A615M, *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement*;
ASTM A706/A706M, *Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement*;
ASTM A767/A767M, *Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement*;
ASTM A775/A775M, *Standard Specification for Epoxy-Coated Steel Reinforcing Bars*;
ASTM A934/A934M, *Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars*;
ASTM A1055/A1055M, *Standard Specification for Zinc and Epoxy Dual Coated Steel Reinforcing Bars*;
ASTM A1094/A1094M, *Standard Specification for Continuous Hot-Dip Galvanized Steel Bars for Concrete Reinforcement*;
ASTM E94, *Standard Guide for Radiographic Examination*;
ASTM E165, *Standard Practice for Liquid Penetrant Examination for General Industry*;
ASTM E709, *Standard Guide for Magnetic Particle Testing*; and
ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*.

Canadian Standards Association standard:

CSA Standard W178.2, *Certification of Welding Inspectors*.

3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, provides the basis for terminology used herein. However, the following terms and definitions are included below to accommodate usage specific to this document.

Contractor. “Contractor” shall be defined as any company, or that individual representing a company, responsible for the fabrication, erection, manufacturing, or welding, in conformance with the provisions of this code.

Engineer. “Engineer” shall be defined as a duly designated individual who acts for and on behalf of the Owner on all matters within the scope of this code.

Inspector(s) (unmodified). When the term “Inspector” is used without further qualification as the specific Inspector category, it applies equally to the Contractor’s Inspector and the Quality Assurance Inspector within the limits of responsibility described in this code.

Owner. “Owner” shall be defined as the individual or company that exercises legal ownership of the product or structural assembly produced under this code.

Quality Assurance Inspector. The “Quality Assurance (QA) Inspector” is the duly designated person who acts for and on behalf of the Engineer and Owner on all matters within the scope of the contract documents and the limit of authority delegated by the Engineer.

Quality Control Inspector. The “Quality Control (QC) Inspector” is the duly designated person who acts for and on behalf of the contractor on inspection, testing, and quality matters within the scope of the contract documents.

4. Design of Welded Joints

4.1 Design Basis

4.1.1 Loads and Load Combinations. The loads and load combinations shall be as stipulated by the applicable building code. In the absence of a building code, the loads and load combinations shall be those stipulated in ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures*.

4.1.2 Strength Design. The design of welded joints shall be based on

$$\Phi R_n \geq R_u$$

where

R_u = required strength using factored load combinations

R_n = nominal strength of the joint

Φ = strength reduction factor

ΦR_n = design strength of the joint

4.1.3 Allowable Strength Design (ASD). The design of welded joints shall be based on

$$R_n/\Omega \geq R_a$$

where

R_a = required strength using nominal load combinations

R_n = nominal strength of the joint

Ω = safety factor

R_n/Ω = allowable strength of the joint

4.1.4 Strength. The design strength, ΦR_n , and the allowable strength, R_n/Ω , of welded joints shall be the weld metal strength determined according to the limit states of rupture as follows:

$$R_n = F_{nw} A_{we}$$

where

F_{nw} = nominal strength of weld metal, ksi [MPa]

A_{we} = effective area of the weld, in² [mm²]

The values of Φ , Ω , and F_{nw} and limitations thereon are given in Table 4.1.

4.2 Effective Weld Areas, Lengths, Throats, and Sizes

4.2.1 Complete Joint Penetration (CJP) Groove Welds in Direct Butt Joints. The effective weld area, A_{we} , shall be the nominal cross-sectional area of the bar being welded (see Figure 5.2). If different reinforcing bar size numbers are being welded, the weld area shall be based on the smaller reinforcing bar.

4.2.2 Flare-Bevel and Flare-V-Groove Welds. The effective weld area, A_{we} , shall be the effective weld length multiplied by the effective throat (see Figure 4.1).

4.2.2.1 Effective Weld Length. The effective weld length shall be the weld length of the specified weld size.

4.2.2.2 Minimum Effective Weld Length. The minimum effective weld length shall not be less than two times the bar diameter for equal size bars or two times the smaller bar diameter for two unequal size bars.

4.2.2.3 Effective Weld Throat. The effective throat, when filled flush to the solid section of the steel reinforcing bar, shall be 0.4 of the bar radius for flare-bevel-groove welds and 0.6 of the bar radius for flare-V-groove welds. Larger effective throats may be used to determine the design strength, provided the WPS qualifies the larger effective throat. When bars of unequal diameter are being joined, the effective throat shall be based on the radius of the smaller bar. See 8.2.6.2 for macroetch test requirements for determining effective throat.

4.2.3 Fillet Welds. The effective weld area, A_{we} , shall be the effective weld length multiplied by the effective throat. Stresses in fillet welds shall be considered as shear applied to the effective weld area for any direction of applied load.

4.2.3.1 Effective Weld Length. The effective weld length of a curved fillet weld shall be measured along the weld axis.

4.2.3.2 Effective Throat. The effective throat shall be calculated as the minimum distance from the joint root to the face of the fillet weld, minus convexity.

4.3 Other Limit States

Other limit states of failure of the base material, including tensile, shear, and block shear are beyond the scope of this code.

Table 4.1
Design Strength and Allowable Strength of Welded Joints (see 4.1.4)

Load Type and Direction Relative to Weld Axis	Weld	Strength-Reduction Factor, ϕ and Safety Factor, Ω	Nominal Strength, F_{nw}	Effective Area, A_{we}	Required Filler Metal Strength Level ^a
Complete Joint Penetration Groove Welds ^b					
Tension normal to weld axis	Strength of the joint is controlled by the base metal				Matching filler metal shall be used
Compression normal to weld axis	Strength of the joint is controlled by the base metal				Filler metal with a strength level equal to or one classification (10 ksi [70 MPa]) less than matching filler metal is permitted
Shear	Strength of the joint is controlled by the base metal				Matching filler metal shall be used
Partial Joint Penetration Groove Welds ^{c,d}					
Flare-Bevel and Flare-V-Groove Welds					
Tension or Compression Parallel to weld axis	Tension or compression in parts joined parallel to a weld need not be considered in design of welds joining the parts				Filler Metal with a strength level equal to or less than matching filler metal is permitted
Shear	Weld	$\phi = 0.75$ $\Omega = 2.00$	$0.60F_{EXX}$	See 4.2.2	
Fillet Welds—External and Internal ^{d,e}					
Shear	Weld	$\phi = 0.75$ $\Omega = 2.00$	$0.60F_{EXX}$	See 4.2.3	Filler metal with a strength level equal to or less than matching filler metal is permitted

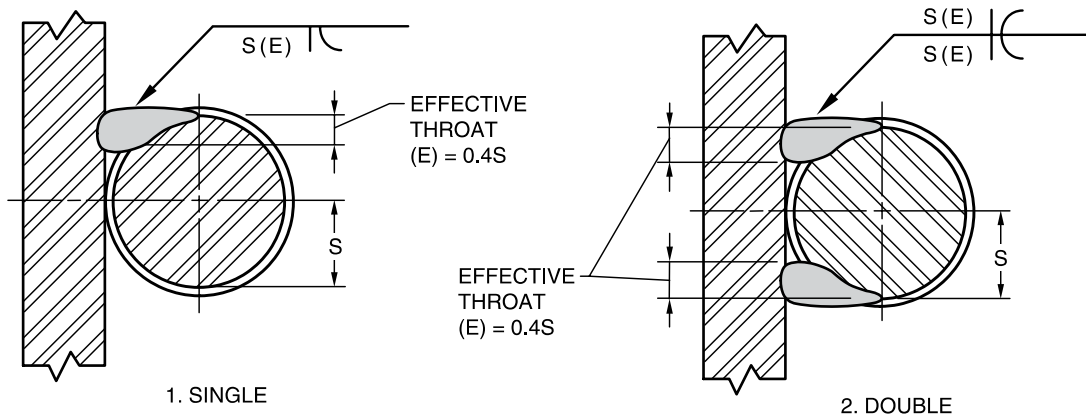
^a For matching filler metal, see Table 7.1.

^b See Figures 5.1, 5.2, and 5.5(D).

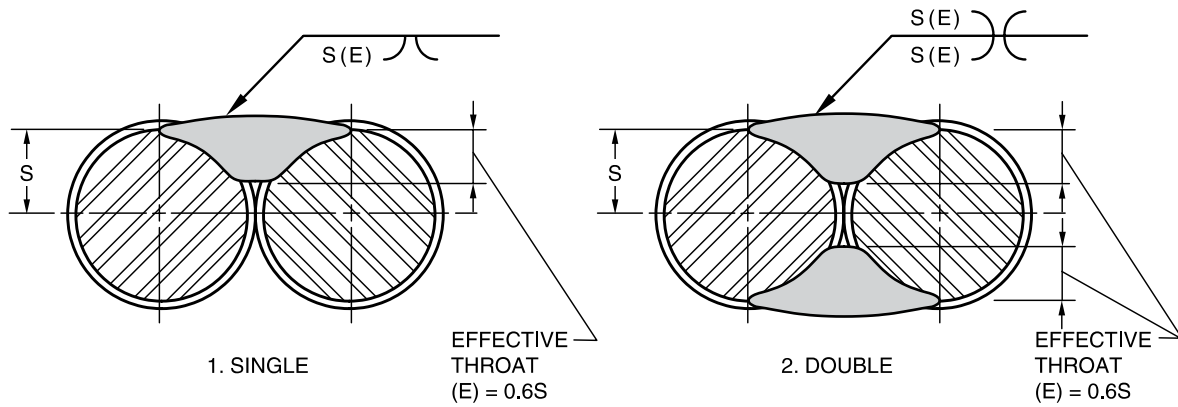
^c See Figures 5.3, 5.4, and 5.5(E).

^d Splices of steel reinforcing bars may need to be designed to develop 125% of the specified yield strength, f_y , of the bars; see applicable building code.

^e See Figure 5.5.



(A) FLARE-BEVEL-GROOVE WELD



(B) FLARE-V-GROOVE WELD

Notes:

1. S = Nominal radius of steel reinforcing bar.
2. E = Effective throat. The throat is the least dimension from the point of fusion in the root to the weld face, less any reinforcement.
3. These are sectional views. Bar deformations are shown only for illustrative purposes.
4. Deformations are not shown for illustration clarity.

Figure 4.1—Effective Throat for Flare-Groove Welds (see 4.2.2)

5. Structural Details

5.1 Transition in Bar Size Number

Direct butt joints in tension in axially aligned bars of different size shall be made as shown in Figure 5.1 (see Annex B for bar size number).

5.2 Joint Types

Steel reinforcing bars may be welded with direct or indirect butt joints, lap joints, or T-joints (Figures 5.1, 5.2, 5.3, 5.4, and 5.5); however, direct butt joints are preferable for bars greater than size No. 6 [19].

5.3 Direct Butt Joints

Table 5.1, Figure 5.2, and Figure 5.5(D) describe the type of welded joints required. For Figure 5.5(D), backgouge to sound metal before welding the other side. For bar size numbers 8 [25] or smaller, the single-bevel weld with backgouging and back welding is recommended.

5.4 Indirect Butt Joints

An indirect butt joint shall be made with either single- or double-flare-groove welds between the bars and the splice member. See Figure 5.3. The welding symbol without S and (E) dimensions indicates the weld shall be filled flush.

5.5 Lap Joints

5.5.1 Direct Lap Joint. A lap joint shall be made with double-flare-V-groove welds [see Figure 5.4(A)], except that single-flare-V-groove welds may be used when the joint is accessible from only one side, and approved by the Engineer.

5.5.2 Indirect Lap Joint. An indirect lap joint shall be made with single flare-bevel groove welds between the bars and the splice plate, with the bars being separated [see Figure 5.4(B)].

5.5.3 Bar Diameter Range. Welded lap joints shall be limited to bar size No. 6 [19] and smaller.

5.5.4 Effects of Eccentricity. The effects of eccentricity shall be considered or restraint provided in the design of the joint.

5.5.5 Filled Flush. The weld symbol without S and (E) dimensions indicates the weld shall be filled flush.

5.6 Lap Joints in an Anchorage

The welding symbol without S and (E) dimensions indicates the weld shall be filled flush [see Figure 5.5(E)].

5.7 Interconnection of Precast Members

Precast members may be interconnected by welding steel reinforcing bars that project through the ends of the precast members or by welding to insert plates that have been cast into the precast members.

Table 5.1 CJP Groove Weld Requirements for Direct Butt Joints (see 5.3)		
Bar Axis Orientation	Types of CJP Groove Weld	Figure 5.2 Detail
Horizontal	Single-V	A
	Double-V	B
	Single-V with Split Pipe Backing	C ^a
Vertical	Single-Bevel	D
	Double-Bevel	E
	Single-bevel with Split Pipe Backing	C ^a

^a Bars shall be of equal diameter.

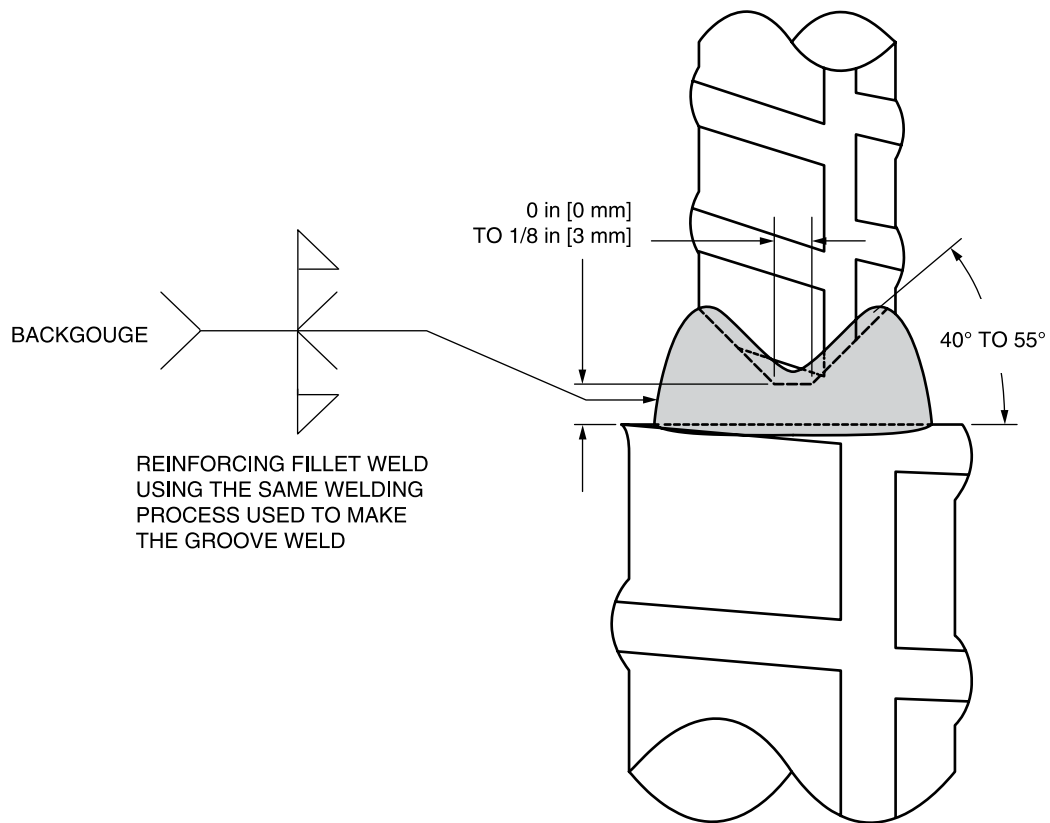


Figure 5.1—Direct Butt Joint Showing Transition Between Bars of Different Sizes (see 5.1)

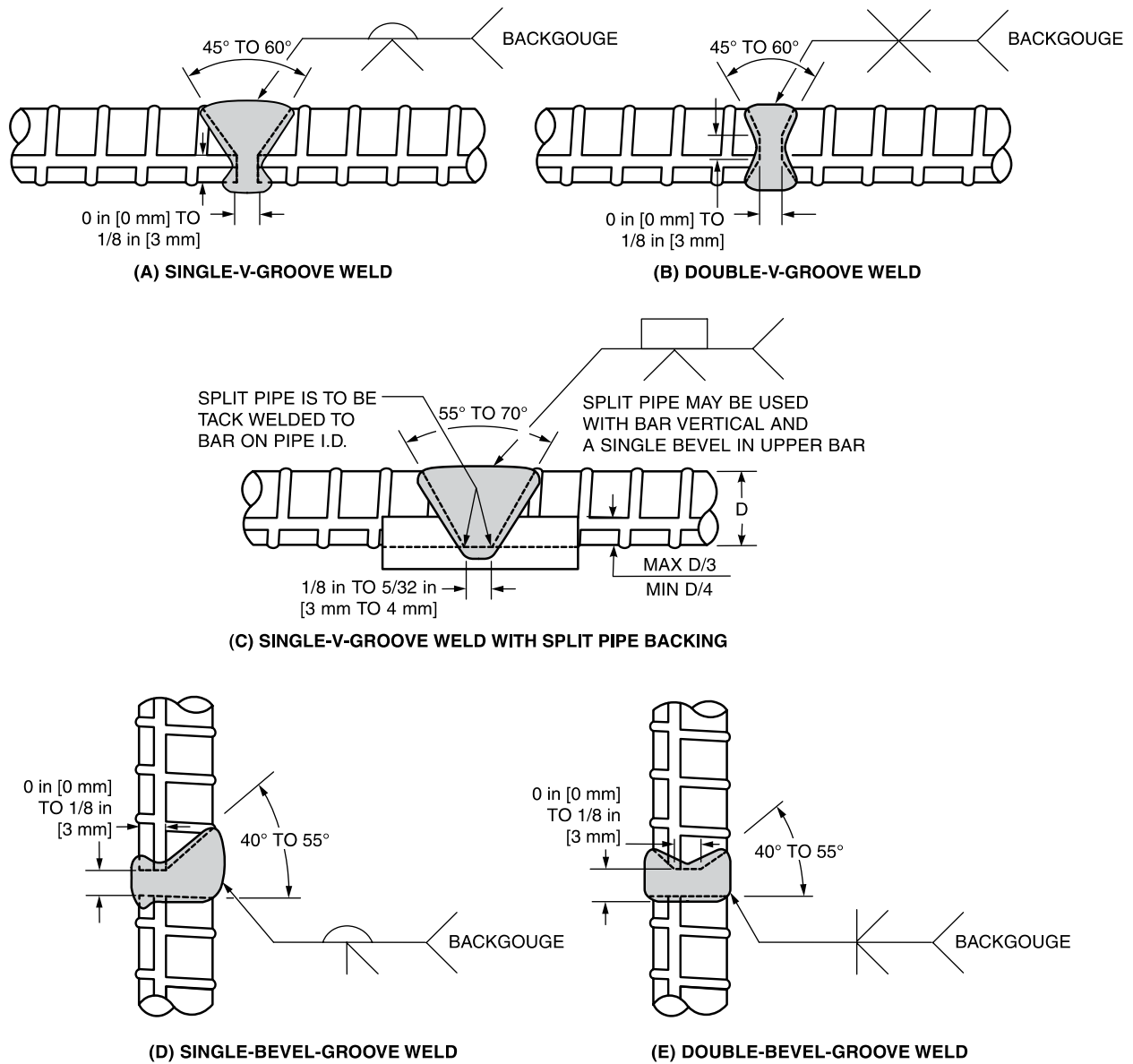
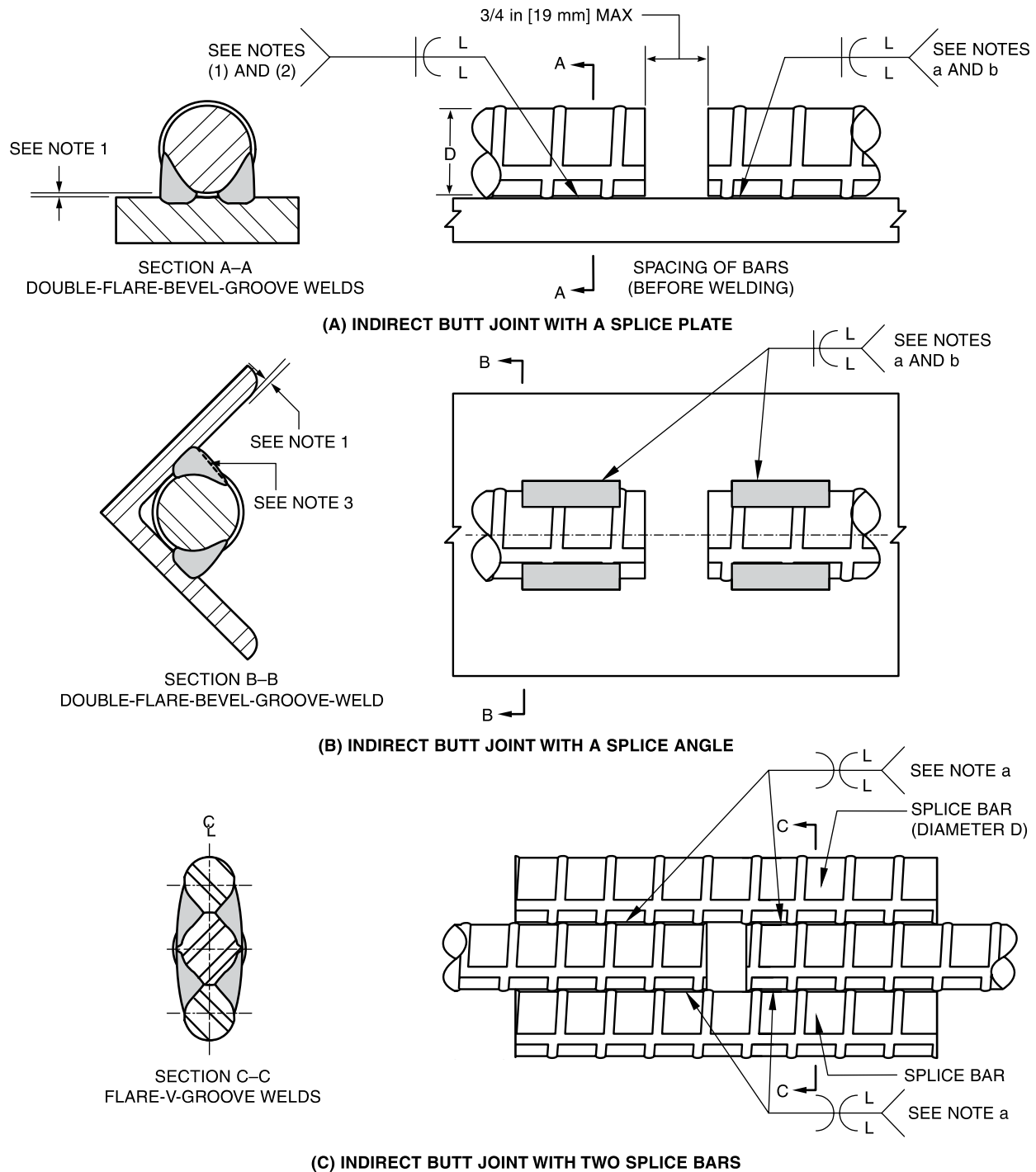


Figure 5.2—Direct Butt Joints (see Table 5.2)



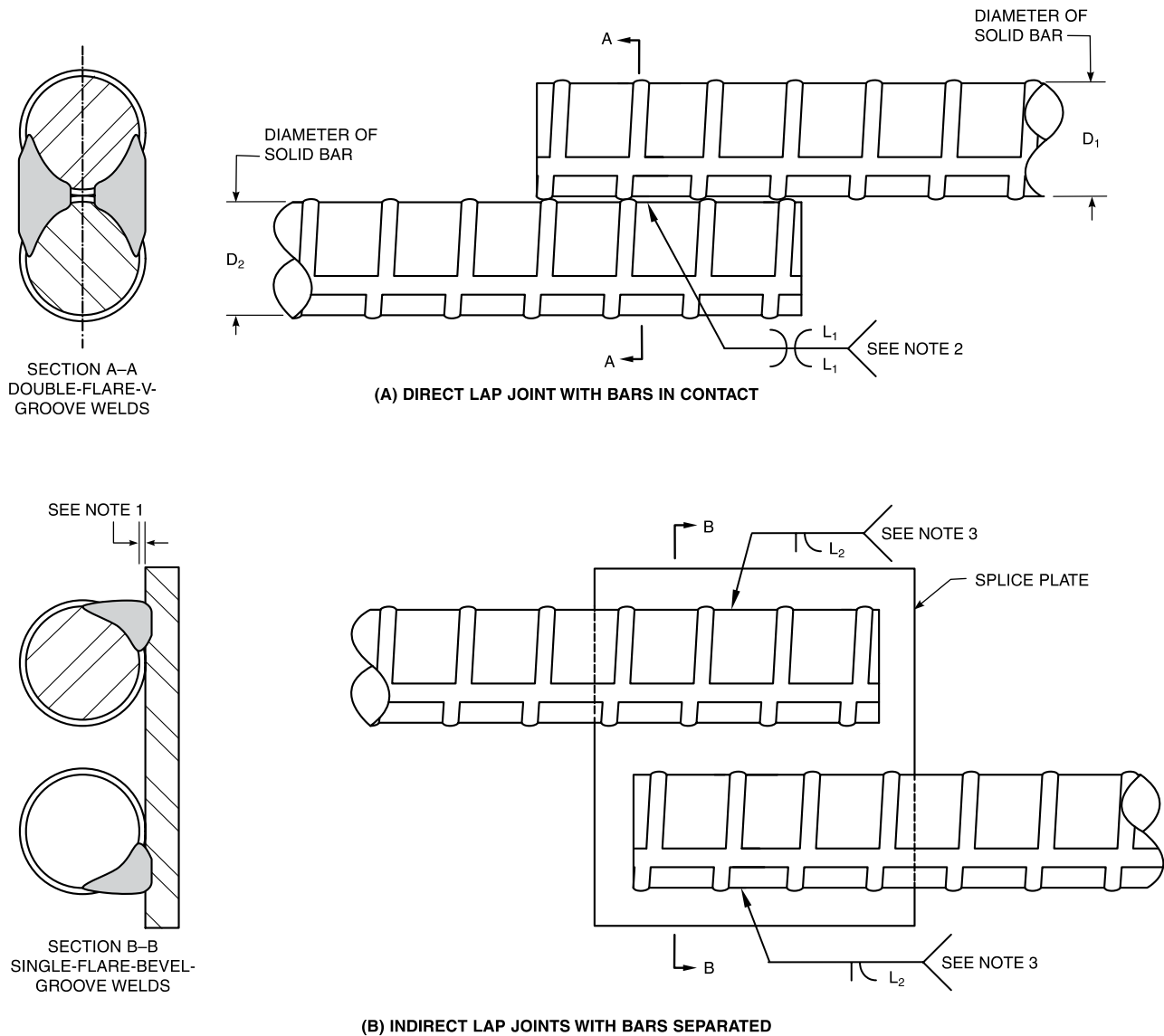
^a $L = 2D$ (min.).

^b Variation of this weld using single flare-V welds is permitted provided eccentricity is considered or restraint provided in the design of the joint.

Notes:

1. Gaps between bars and plate will vary depending on height of deformations but shall not exceed $1/4 D$ or $3/16$ in [5 mm], whichever is less.
2. Deformations shown on sectional views are for illustrative purposes only.
3. Fill flush to bar tangent.

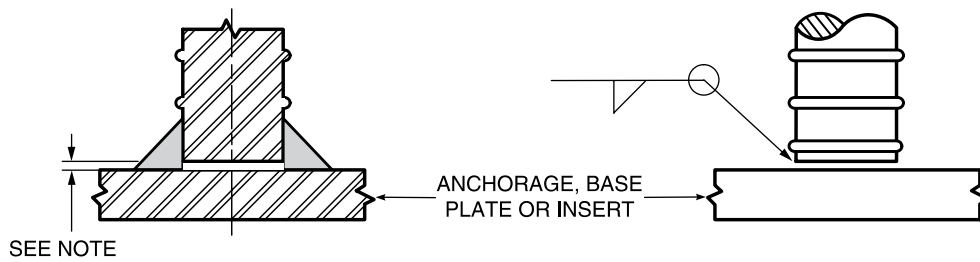
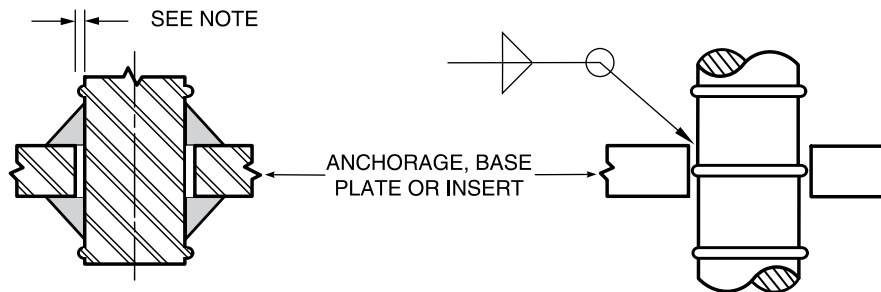
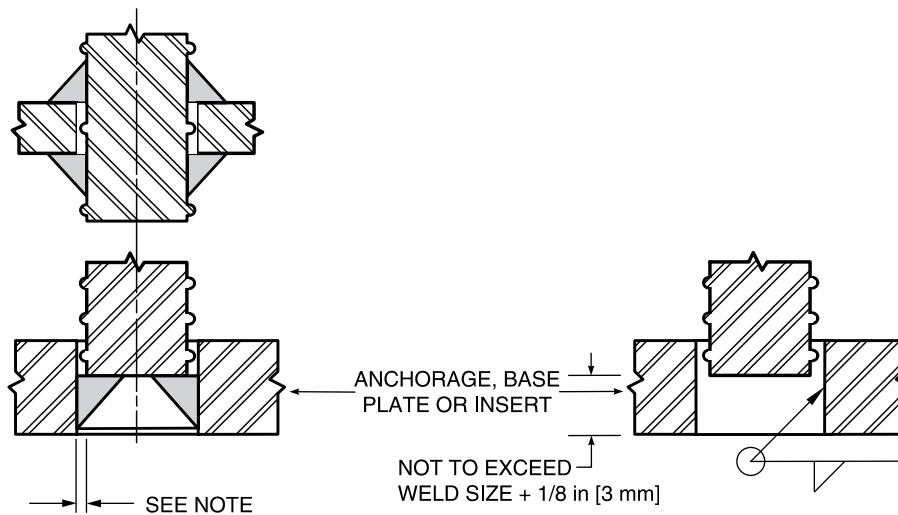
Figure 5.3—Indirect Butt Joints (see 5.4)



Notes:

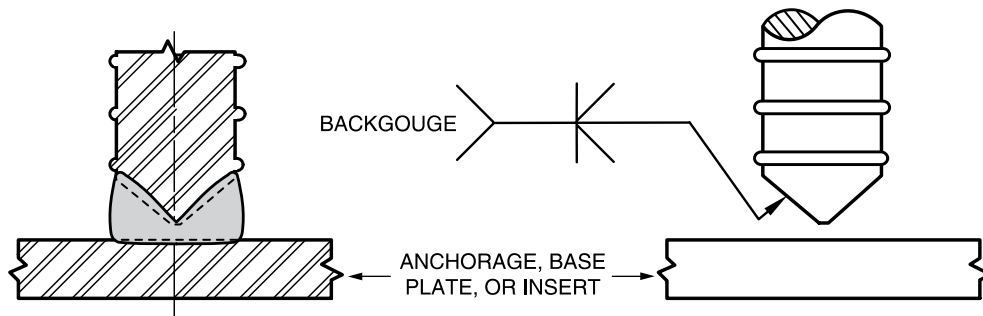
1. Gaps between bars and plate will vary depending on height of deformations but shall not exceed $1/4 D$ or $3/16$ in [5 mm], whichever is less (see 6.2.4).
2. $L_1 = 2 D_1$ (min); $D_1 \sim D_2$
3. $L_2 = 2 \times$ diameter of bar (min.).

Figure 5.4—Lap Joints (see 5.5.1 and 5.5.2)

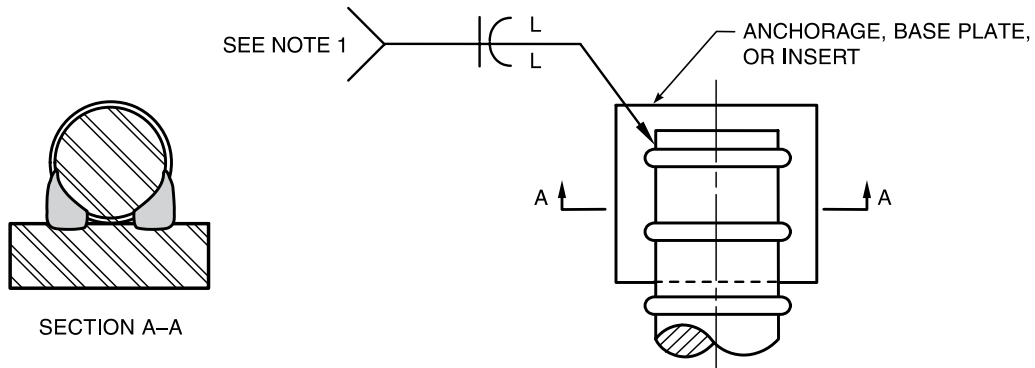
**(A) EXTERNAL FILLET WELD****(B) EXTERNAL FILLET WELD****(C) INTERNAL FILLET WELD**

Note: Gaps between bars and plate will vary depending on height of deformations but shall not exceed $1/4 D$ or $3/16$ in [5 mm], whichever is less.

Figure 5.5—Details of Joints of Anchorages, Base Plates, and Inserts (see 5.4)



**(D) COMPLETE JOINT PENETRATION
GROOVE WELD —T-JOINT (SEE 5.3)**



**(E) LAP JOINTS IN AN ANCHORAGE
USING FLARE-BEVEL-GROOVE WELDS**

Note:

1. $L = 2 \times \text{bar diameter (min.)}$.

Figure 5.5 (Continued)—Details of Joints of Anchorages, Base Plates, and Inserts (see 5.4)

6. Workmanship

6.1 Preparation of Base Metal

6.1.1 General. Base metal shall be sufficiently clean to permit welds to be made that will meet the quality requirements of this code.

6.1.2 Mill-Induced Surface Defects. Welds shall not be placed on surfaces that contain fins, tears, cracks, slag, or other base metal defects as defined in the base metal specifications.

6.1.3 Scale and Rust. Loose scale, thick scale, and thick rust shall be removed from the surfaces to be welded and from surfaces adjacent to the weld. Welds may be made on surfaces that contain mill scale and rust if the mill scale and rust can withstand vigorous hand wire brushing and if the applicable quality requirements of this code can be met.

6.1.4 Foreign Materials

6.1.4.1 Foreign Material Exclusion. Surfaces to be welded, and surfaces adjacent to the weld, shall be cleaned to remove excessive quantities of the following:

- Water
- Oil
- Grease
- Other hydrocarbon based materials

Welding on surfaces containing residual amounts of foreign materials is permitted providing the quality requirements of this code can be met.

6.1.4.2 Permissible Foreign Material. Welds are permitted to be made on surfaces with surface protective coatings or anti-spatter compounds, except those that are prohibited in 6.1.4.1, provided the quality requirements of this code can be met.

6.1.5 Coatings. All coatings shall be removed within 2 in [50 mm] of the faying surface of the weld joint.

6.1.6 Preparation of Groove Welds. The ends of steel reinforcing bars in direct butt joints shall be shaped to form the weld groove by thermal cutting, air carbon arc cutting, sawing, or other mechanical means. Roughness of oxygen cut surfaces shall be no greater than the 2000 μ in [50 μ m] limit defined in AWS C4.1, *Criteria for Describing Oxygen-Cut Surfaces*. Roughness exceeding this value and occasional notches or gouges not more than 3/16 in [5 mm] deep, on otherwise satisfactory surfaces, shall be removed by machining or grinding. Bars for direct butt joints that have sheared ends shall be trimmed back beyond the area deformed by shearing.

6.2 Assembly

6.2.1 Alignment. The joint members shall be aligned to minimize eccentricities. Welded direct butt joints shall not be offset at the joint by more than the following:

Bar sizes No. 10 [32] or smaller	1/8 in [3 mm]
Bar sizes No. 11 [36] and No. 14 [43]	3/16 in [5 mm]
Bar size No. 18 [57]	1/4 in [6 mm]

6.2.2 Indirect Lap Joint Separation. For indirect lap joints [see Figure 5.4(B)], the maximum separation between the bar and the splice plate shall be no more than one-quarter of the bar diameter, but not more than 3/16 in [5 mm].

6.2.3 Cross Welding Bars. Welding of bars that cross shall not be permitted unless authorized by the Engineer.

6.2.4 Termination of Welds on Radius. Welds made on the unbent portion of cold-bent steel reinforcing bar shall be terminated or initiated at a minimum distance of two bar diameters from the points of tangency for the radius created by cold bending. See Figure 6.1.

6.3 Control of Distortion, Shrinkage, and Heat

6.3.1 Distortion and Shrinkage. In assembling and joining parts of a structure or precast member, the procedure and sequence followed shall minimize distortion and shrinkage.

6.3.2 Thermal Expansion. When welding is performed on bars or other structural components that are already embedded in concrete, allowance shall be made for thermal expansion of the steel to prevent spalling or cracking of the concrete or significant destruction of the bond between the concrete and the steel. The heat of welding may cause localized damage to the concrete.

6.4 Quality of Welds

Welds that do not meet the quality requirements of 6.4.1 through 6.4.9, inclusive, shall be repaired by removal of unacceptable portions or by rewelding, whichever is applicable.

6.4.1 Weld Face. The fillet weld faces shall be slightly convex or slightly concave as shown in Figures 6.2(A) or flat, and with none of the unacceptable profiles exhibited in Figure 6.2(B). Groove weld profiles shall conform to Figures 6.2(C) or (E) with none of the unacceptable profiles exhibited in Figures 6.2(D) or (F).

6.4.2 No Cracks. Any crack shall be unacceptable, regardless of size or location.

6.4.3 Complete Fusion. There shall be complete fusion between weld metal and base metal and between successive passes in the weld.

6.4.4 Craters. All weld craters shall be filled to a cross section that meets the minimum specified weld size.

6.4.5 Overlap. Welds shall be free from overlap.

6.4.6 Undercut. Undercut depth greater than 1/32 in [1 mm] in the solid section of the bar or structural member shall not be allowed.

6.4.7 Piping Porosity. The sum of diameters of piping porosity shall not exceed 3/8 in [10 mm] in any linear inch [25 mm] of weld and shall not exceed 9/16 in [14 mm] in any 6 in [150 mm] length of weld.

6.4.8 Weld Size. The weld size shall be equal to or greater than the weld size specified [for flare-groove welds, see Figure 8.8 for effective throat (E) and if no S or (E) dimension is specified, see Figure 4.1 for required size]. The length of weld containing this weld size shall be equal to or greater than the weld length specified. Any portion of the length, including starts or stops, that contains a smaller weld size shall not be measured in the weld length.

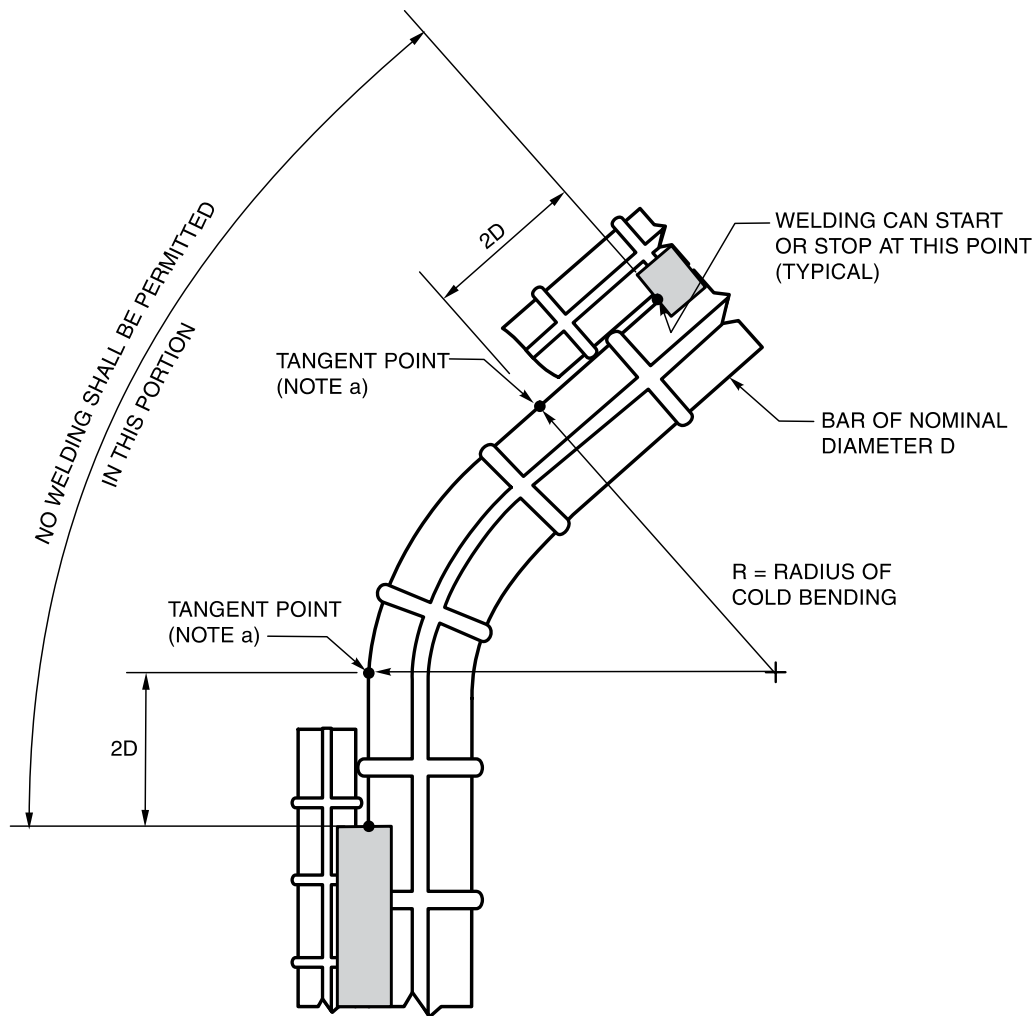
6.4.9 Direct Butt Radiographic Inspection. When radiographic inspection of direct butt joints is required, the maximum dimension of any single porosity or fusion-type discontinuity, or the sum of the maximum dimensions of all porosity or fusion-type discontinuities, shall not exceed the limits given in Table 6.1. For radiographic inspection, see 9.7.3.

6.4.10 Repairs. Repairs to welds made with the shielded metal arc welding (SMAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), or gas tungsten arc welding (GTAW) processes shall be made in accordance with a qualified WPS approved by the Engineer.

Table 6.1
Radiographic Acceptance Criteria^a (see 6.4.9)

Bar Size Number	Sum of the Maximum Dimensions of all Porosity or Fusion-Type Discontinuities		Maximum Dimension of Any Single Porosity or Fusion-Type Discontinuity	
	in	mm	in	mm
8 [25]	3/16	5	1/8	3
9 [29]	3/16	5	1/8	3
10 [32]	1/4	6	1/8	3
11 [36]	1/4	6	3/16	5
14 [43]	5/16	8	3/16	5
18 [57]	7/16	11	1/4	6

^a Acceptance criteria for bar size numbers less than size No. 8 [25] shall be established by the Engineer.



^a For welding on inside radius, use tangent points on inside radius.

Note: This figure is for illustration only.

Figure 6.1—Minimum Distance to Cold Bending Radius Tangent Points (see 6.2.4)

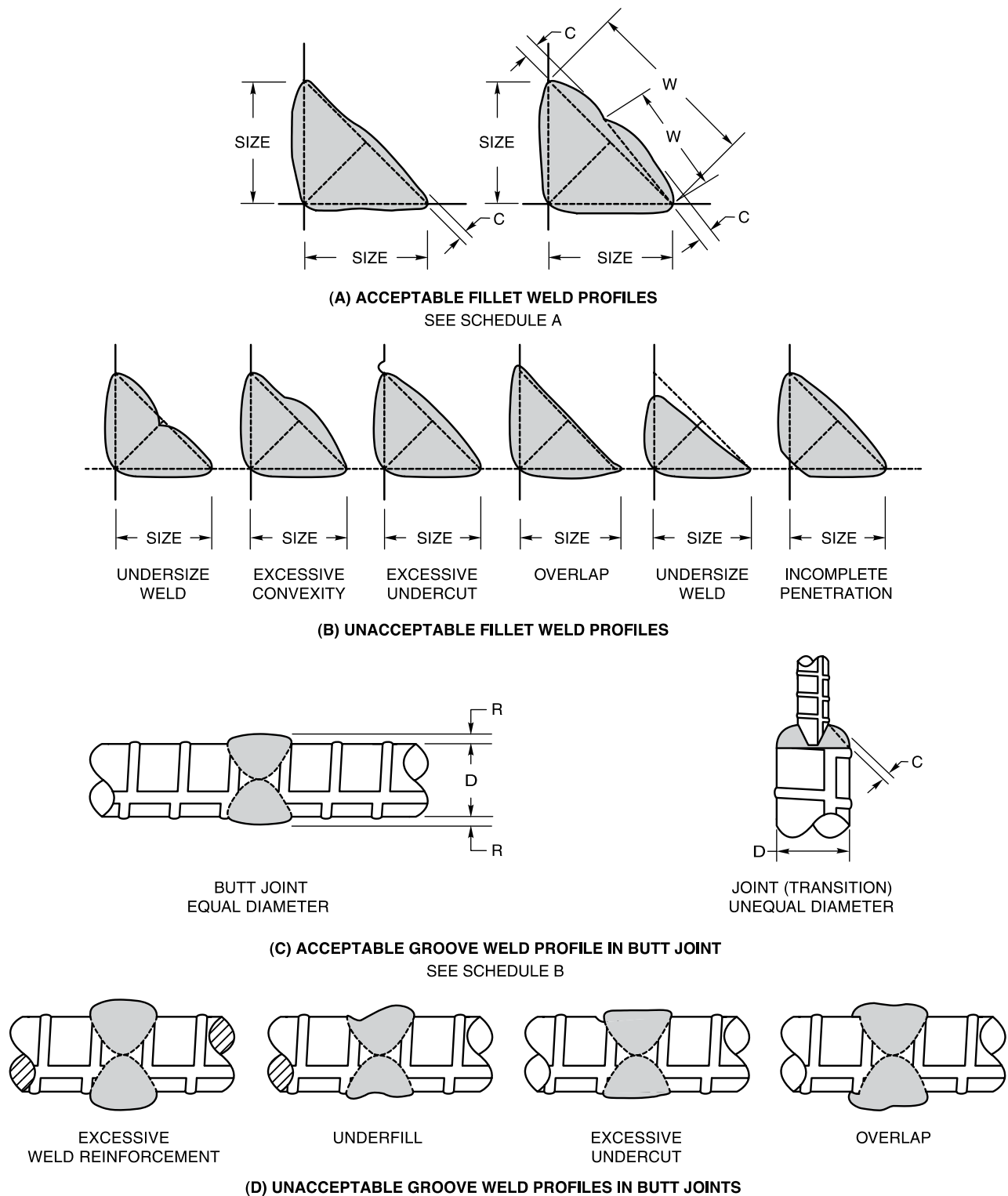
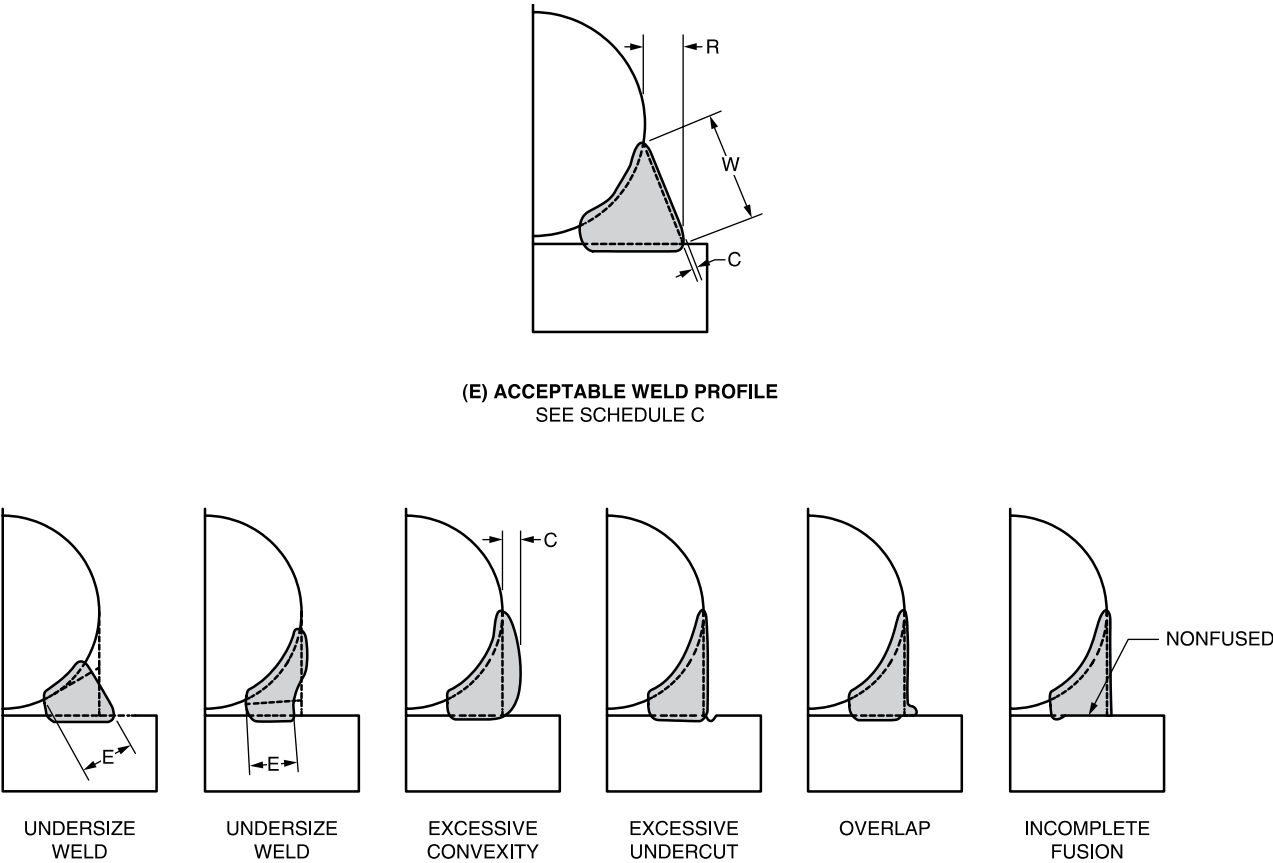


Figure 6.2—Acceptable and Unacceptable Weld Profiles (see 6.4.1)



(F) UNACCEPTABLE GROOVE WELD PROFILES

Note: See schedules below for maximum and minimum values for convexity (C) and reinforcement (R) E is effective throat, see Figure 6.8.

SCHEDULE A	WIDTH OF WELD FACE OR INDIVIDUAL SURFACE BEAD, W	C max.	C min.	R max.	R min.
	W ≤ 5/16 in [8 mm]	1/16 in [2 mm]	0	N/A	N/A
	W > 5/16 in [8 mm] TO W < 1 in [25 mm]	1/8 in [3 mm]	0	N/A	N/A
	W ≥ 1 in [25 mm]	3/16 in [5 mm]	0	N/A	N/A
SCHEDULE B	DIAMETER OF STEEL REINFORCING BAR, D	C max.	C min.	R max.	R min.
	D ≤ 1 in [25 mm]	1/8 in [3 mm]	0	1/8 in [3 mm]	0
	D > 1 in [25 mm] TO D < 2 in [50 mm]	1/8 in [3 mm]	0	3/16 in [5 mm]	0
	D ≥ 2 in [50 mm]	3/16 in [5 mm]	0	1/4 in [6 mm]	0
SCHEDULE C	WIDTH OF WELD FACE OR INDIVIDUAL SURFACE BEAD, W	C max.	C min.	R max.	R min.
	W ≤ 5/16 in [8 mm]	1/16 in [2 mm]	0	unlimited	0
	W > 5/16 in [8 mm] TO W < 1 in [25 mm]	1/8 in [3 mm]	0	unlimited	0
	W ≥ 1 in [25 mm]	3/16 in [5 mm]	0	unlimited	0

Figure 6.2 (Continued)—Acceptable and Unacceptable Weld Profiles

7. Technique

7.1 Filler Metal Requirements

7.1.1 Filler Metal/Base Metal Relationship. For any connections welded in accordance with this code, the base metal–filler metal strength relationship below shall be used in conjunction with Table 7.1 to determine whether matching or undermatching filler metals are required.

Filler Metal/Base Metal Relationships		
Relationship	Base Metal	Strength Required
Matching	Any <u>steel</u> reinforcing <u>bar</u> to itself or any <u>steel</u> reinforcing <u>bar</u> to any other steel <u>in the same group</u>	Any filler metal listed in the same Table 7.1 strength group
	Any <u>steel</u> reinforcing <u>bar</u> in one group to any <u>steel</u> reinforcing <u>bar</u> or other steel <u>in another</u>	Any filler metal listed for <u>either</u> Table 7.1 strength group [<u>SMAW electrodes shall be the low-hydrogen classification</u>]
Undermatching	Any <u>steel</u> reinforcing <u>bar</u> to a <u>steel</u> reinforcing <u>bar</u> or other steel <u>in any group</u>	Any filler metal listed for the next lower Table 7.1 strength group.

Note: See Table 4.1 to determine the filler metal strength requirements to match or undermatch base metal strength.

7.1.2 Coated Bars. For coated steel reinforcing bars conforming to ASTM A767/A767M, ASTM A775/A775M, ASTM A934/A934M, ASTM A1055/A1055M, *Specification for Zinc and Epoxy Dual-Coated Steel Reinforcing Bars*, or ASTM A1094/A1094M, *Specification for Hot-Dipped Galvanized Steel Bars for Concrete Reinforcement*, filler metal selection shall be based upon the requirements of the grade (minimum yield strength) of the uncoated steel reinforcing bars.

7.2 Minimum Preheat and Interpass Temperature Requirements

7.2.1 Preheat and Interpass Temperature. Minimum preheat and interpass temperatures shall be in accordance with Table 7.2 using the highest carbon equivalent number of the base metal as determined in accordance with 1.5.4.

7.3 Welding Environment

7.3.1 Maximum Wind Velocity. GMAW, GTAW, or FCAW-G shall not be done in a draft or wind unless the weld is protected by a shelter. Such shelter shall be of material and shape appropriate to reduce wind velocity in the vicinity of the weld to a maximum of five miles per hour [eight kilometers per hour].

7.3.2 Environmental Conditions. Welding shall not be done

- (1) when the ambient temperature is lower than 0°F [−20°C], or
- (2) when surfaces are wet or exposed to rain, snow, or
- (3) high wind velocities, or
- (4) when welding personnel are exposed to inclement conditions.

NOTE: 0°F does not mean the ambient environmental temperature, but the temperature in the immediate vicinity of the weld. The ambient environmental temperature may be below 0°F [−20°C], but a heated structure or shelter around the area being welded may maintain the temperature adjacent to the weldment at 0°F [−20°C] or higher.

7.4 Arc Strikes

Cracks or blemishes caused by arc strikes shall be ground to a smooth contour and checked to ensure soundness.

7.5 Weld Cleaning

7.5.1 In-Process Cleaning. Before welding over previously deposited metal, all slag shall be removed and the weld and adjacent base metal shall be brushed clean. This requirement shall apply not only to successive layers but also to successive beads and to the crater area when welding is resumed after any interruption.

7.5.2 Cleaning of Completed Welds. Slag shall be removed from all completed welds, and the weld and adjacent base metal shall be cleaned by brushing or other suitable means. Tightly adherent spatter remaining after the cleaning operation is acceptable, unless its removal is required for the purpose of NDT or coating. Welded joints shall not be painted until after welding has been completed and the weld accepted.

7.6 Tack Welds

Tack welds that do not become a part of permanent welds shall be prohibited unless authorized by the Engineer. Tack welds shall be subject to the welding requirements of this code, including preheat, electrode selection, and discontinuity acceptance criteria.

7.7 Progression of Welding

Welds made in the vertical position [Figure 8.1(C), Position 3G or Figure 8.2(C), Position 3G], shall use uphill progression.

7.8 Welding of Coated Base Metal

7.8.1 Coated Base Metal. After welding to a qualified WPS, suitable coating protection shall be applied to the finished joint to restore the corrosion-resistant properties of the coated bars.

7.8.2 Galvanized Base Metal. When welding galvanized base metal, one of the following options shall be met:

7.8.2.1 Option 1. Welding of galvanized base metal may be done after removing all coating from within 2 in [50 mm] of the weld joint. In this option, the welding shall be performed using a WPS for coated or uncoated steel reinforcing bar qualified in accordance with this code. The galvanized coating may be removed with oxyfuel gas flame, abrasive shot blasting, or other suitable means.

7.8.2.2 Option 2. Welding of galvanized base metal, without prior removal of the coating, shall be performed in accordance with a WPS qualified to the requirements of this code. Note that the WPS will normally involve larger root openings in joints, electrodes with lower silicon content, and slower welding speeds.

7.8.3 Epoxy-Coated Base Metal. When welding or preheating epoxy-coated base metal, the epoxy coating shall be removed as required for the measurement of preheat but no less than a half an inch [13 mm].

7.9 SMAW Electrodes

Electrodes for SMAW shall conform to the requirements of the latest edition of AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding Electrodes*, or to the requirements of AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*.

7.9.1 Low-Hydrogen Electrode Storage Conditions. All electrodes having low-hydrogen coverings conforming to AWS A5.1/A5.1M and AWS A5.5/A5.5M shall be purchased in hermetically sealed containers or shall be baked prior to use. Immediately after opening the hermetically sealed container, electrodes shall be stored in ovens held at a temperature of at least 250°F [120°C].

7.9.2 Approved Atmospheric Time Periods. After hermetically sealed containers are opened or after electrodes are removed from baking or storage ovens, the electrode exposure to the atmosphere shall not exceed the values shown in

column A, Table 7.3, for the specific electrode classification with optional supplemental designators, where applicable. Electrodes exposed to the atmosphere for periods less than those permitted by column A, Table 7.3 may be returned to a holding oven maintained at 250°F [120°C] min.; after a minimum hold period of four hours at 250°F [120°C] min., the electrodes may be reissued. Electrodes that have been wet shall not be used.

7.9.3 Alternative Atmospheric Exposure Time Periods Established by Tests. The alternative exposure time values shown in column B in Table 7.3 may be used, provided testing establishes the maximum allowable time. The testing shall be performed in conformance with AWS A5.5/A5.5M for each electrode classification and each electrode manufacturer. Such tests shall establish that the maximum moisture-content values of AWS A5.5 are not exceeded. Additionally, E70XX or E70XX-X (AWS A5.1/A5.1M or A5.5/A5.5M) low-hydrogen electrode coverings shall be limited to a maximum moisture content not exceeding 0.4% by weight. These electrodes shall not be used at relative humidity–temperature combinations that exceed either the relative humidity or moisture content in the air that prevailed during the testing program.

For proper application to this provision, see Annex C for the temperature–moisture content chart and its examples. The chart shown in Annex C, or any standard psychrometric chart, shall be used in the determination of temperature–relative humidity limits.

7.9.4 Rebaking Electrodes. Electrodes exposed to the atmosphere for periods greater than those permitted in Table 7.3 shall be rebaked as follows:

- (1) All electrodes having low-hydrogen coverings conforming to AWS A5.1/A5.1M shall be baked for at least two hours between 500°F [260°C] and 800°F [430°C], or
- (2) All electrodes having low-hydrogen coverings conforming to AWS A5.5/A5.5M shall be baked for at least one hour at temperatures between 700°F [370°C] and 800°F [430°C].

Electrode shall be rebaked no more than once.

7.9.5 Electrode Restrictions for ASTM A514 or A517 Steels. When used for welding steel reinforcing bars to ASTM A514 or A517 steels, electrodes of any classification lower than E100XX-X, except for E7018M and E70XXH4R, shall be baked at least one hour at temperatures between 700°F and 800°F [370°C and 430°C] before being used, whether furnished in hermetically sealed containers or otherwise.

7.10 GMAW Electrodes

Solid or metal cored electrodes for GMAW shall conform to the requirements of the latest edition of AWS A5.18/A5.18M, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*, AWS A5.28/A5.28M, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*, or AWS A5.36/A5.36M, *Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding*, for carbon and low alloy metal core electrodes.

7.11 FCAW Electrodes

Electrodes for FCAW shall conform to the requirements of the latest edition of AWS A5.20/A5.20M, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*, AWS A5.29/A5.29M, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*, or AWS A5.36/A5.36M, *Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding*, for carbon and low alloy metal core electrodes.

7.12 GTAW Electrodes and Filler Metals

7.12.1 Tungsten Electrodes. Welding current shall be compatible with the diameter and type or classification of electrode. Tungsten electrodes shall be in conformance with AWS A5.12M/A5.12 (ISO 6848:2004 MOD), *Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting*.

7.12.2 Filler Metal. The filler metal shall conform to all other requirements of the latest edition of AWS A5.18/A5.18M, Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding or AWS A5.28/A5.28M, Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding, as applicable.

7.13 Shielding Gas

A gas or gas mixture used for shielding shall conform to the requirements of AWS A5.32M/A5.32 (ISO 14175:2008 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*. When requested by the Engineer, the Contractor or fabricator shall furnish the gas manufacturer's certification that the gas or gas mixture conforms to the dew point requirements of AWS A5.32M/A5.32 (ISO 14175:2008 MOD). When mixed at the welding site, suitable meters shall be used for proportioning the gases. Percentage of gases shall conform to the requirements of the WPS.

Table 7.1
Matching Filler Metal Requirements (see 7.1)

Material Group	Steel Specification	Welding Process	AWS A5 Electrode Specification	Electrode Classifications ^a	Additional Comments
I	ASTM A615 Grade 40 ASTM A615M Grade 300	SMAW	A5.1/A5.1M	E7015, E7016, E7016-1, E7018, E7018-1, E7018M, E7028, E7048	
		SMAW	A5.5/A5.5M	E7015-X, E7016-X, E7018-X	
			A5.18/A5.18M	ER70S-X; E70C-XC, E70C-XM	
				Carbon Steel Classifications ^c E70C-6M	
		GMAW	A5.36/A5.36M ^b	Open Classifications ^d E7XT15-C1A2-CS1 E7XT15-M21A2-CS1, E7XTX-XAX-CS1, E7XTX-XAX-CS2	Electrodes with the –GS suffix shall be excluded
			A5.28/A5.28M	ER70S-XXX; E70C-XXX	
		GMAW	A5.36/A5.36M ^b	Low Alloy Open Classifications ^d E7XTX-XAX-X	
		GTAW	A5.18/A5.18M	ER70S-X, E70C-XC, E70C-XM	
		GTAW	A5.28/A5.28M	ER70S-XXX, E70C-XXX	
			A5.20/A5.20M	E7XT-X; E7XT-XC, E7XT-XM	Electrodes with the –2C, –2M, –3, –10, –13, –14, and –GS suffix shall be excluded, and electrodes with the –11 suffix shall be excluded for welds on <u>steel reinforcing bars</u> larger than bar size number 6 [9] or to steel greater than 1/2 in [12 mm] thick
				Carbon Steel Fixed Classifications ^c E7XT-1C, E7XT-1M E7XT-5C, E7XT-5M E7XT-6 E7XT-8 E7XT-9C, E7XT-9M E7XT-12C, E7XT-12M E70T-4 E7XT-7	
		FCAW	A5.36/A5.36M ^b	Open Classifications ^{c,d} E7XTX-C1AX-CS1, E7XTX-M21AX-CS1 ^d , E7XTX-C1AX-CS2, E7XTX-M21AX-CS2 ^d , E7XTX-XAX-CS1, E7XTX-XAXCS2, E7XTX-AX-CS3	(Flux Code Electrodes with the T1S, T3S, T10S, T14S, and –GS suffix shall be excluded and electrodes with the T11 suffix shall be excluded for thicknesses greater than 1/2 in [12 mm].)
			A5.29/A5.29M	E7XTX-X, E7XTX-XC, E7XTX-XM	
		FCAW	A5.36/A5.36M ^b	Low Alloy Open Classifications E7XTX-C1AX-X, E7XTX-M21AX-X ^c E7XTX-XAX-X E7XTX-AX-X	

(Continued)

Table 7.1 (Continued)
Matching Filler Metal Requirements (see 7.1)

Material Group	Steel Specification	Welding Process	AWS A5 Electrode Specification	Electrode Classifications ^a	Additional Comments
II	ASTM A706 Grade 60 ASTM A706M Grade 420	SMAW	A5.5/A5.5M	E8015-X, E8016-X, E8018-X	
			A5.28/A5.28M	ER80S-XXX; E80C-XXX	
		GMAW	<u>A5.36/A5.36M^b</u>	<u>Low Alloy Open Classification^d</u> <u>E8XTX-XAX-X</u>	
			<u>GTAW</u>	<u>A5.28/A5.28M</u>	<u>ER80S-XXX, E80C-XXX</u>
		FCAW	A5.29/A5.29M	E8XTX-X, E8XTX-XC, E8XTX-XM	
			<u>A5.36/A5.36M^b</u>	<u>Low Alloy Open Classifications^{c,d}</u> <u>E8XTX-C1AX-X</u> , <u>E8XTX-M21AX-X</u> <u>E8XTX-XAX-X</u> <u>E8XTX-AX-X</u>	
III	ASTM 615 Grade 60 ASTM A615M Grade 420	SMAW	A5.5/A5.5M	E9015-X, E9016-X, E9018-X, E9018M	
			A5.28/A5.28M	ER90S-XXX; E90C-XXX	
		GMAW	<u>A5.36/A5.36M^b</u>	<u>Low Alloy Open Classifications^d</u> <u>E9XTX-XAX-X</u>	
			<u>GTAW</u>	<u>A5.28/A5.28M</u>	<u>ER90S-XXX, E90C-XXX</u>
		FCAW	A5.29/A5.29M	E9XTX-X, E9XTX-XC, E9XTX-XM	
			<u>A5.36/A5.36M</u>	<u>Low Alloy Open Classifications^{c,d}</u> <u>E9XTX-C1AX-X</u> <u>E9XTX-M21AX-X^c</u> <u>E9XTX-XAX-X</u> <u>E9XTX-AX-X</u>	
IV	ASTM A615 Grade 75 ^b ASTM A615M Grade 520 ^c	SMAW	A5.5/A5.5M	E10015-X, E10016-X, E10010-X, E10018M	
			A5.28/A5.28M	ER100S-XXX; E100C-XXX	
		GMAW	<u>A5.36/A5.36M^b</u>	<u>Low Alloy Open Classifications^d</u> <u>E11TX-XAX-XXX</u>	
			<u>GTAW</u>	<u>A5.28/A5.28M</u>	<u>ER100S-XXX, E100C-XXX</u>
		FCAW	A5.29/A5.29M	E10XTX-XC, E10XTX-XM	
			<u>A5.36/A5.36M^b</u>	<u>Low Alloy Open Classifications^{c,d}</u> <u>E11TX-XAX-XXX</u>	

^a Filler metals of alloy group B3, B3L, B4L, B5, B5L, B6, B6L, B7, B7L, B8, B8L, or B9 in AWS A5.5, A5.28, or A5.29 may be used when given prior approval by the Engineer. Consideration shall be made of the differences in tensile strength, ductility, and hardness between the PWHT versus as-welded conditions.

^b Any AWS A5.36/A5.36M FCAW or GMAW-Metal Core filler metal may be "PREQUALIFIED" if classified in the "AS-WELDED" condition and meets all of the required filler metal classification mechanical properties for the steel reinforcing bar grade, regardless of alloy, as permitted in this code.

^c The prequalified Argon based shielding gases for carbon and low alloy steel FCAW, and carbon steel GMAW-Metal Core Fixed Classifications shall be M21(SG-AC-20/25), see 7.12.2.

^d For open classifications for carbon and low alloy steel FCAW and GMAW-metal core electrodes, the electrodes classified with the previous shielding gas requirements of AWS A5.18, A5.20, A5.28, and A5.29 shall be considered as prequalified and other shielding gases listed in Table 5 of AWS A5.36/A5.36M used for classification of an electrode, but only the specific shielding gas used for classification and not the range of the shielding gas designator, see 7.13.

Table 7.2
Minimum Preheat and Interpass Temperatures^{a, b} (see 7.2.1)

Carbon Equivalent (C.E.) Range, % ^{c, d}	Size of <u>Steel</u> Reinforcing Bar	SMAW with Low-Hydrogen Electrodes, GMAW, FCAW, <u>or</u> GTAW	
		Minimum Temperature	
		°F	°C
Up to 0.40	Up to 11 [36] inclusive	none ^e	none ^e
	14 and 18 [43 and 57]	50	10
Over 0.40 to 0.45 inclusive	Up to 11 [36] inclusive	none ^e	none ^e
	14 and 18 [43 and 57]	50	10
Over 0.45 to 0.55 inclusive	Up to 6 [19] inclusive	none ^e	none ^e
	7 to 11 [22 to 36]	50	10
	14 to 18 [43 to 57]	200	90
Over 0.55 to 0.65 inclusive	Up to 6 [19] inclusive	100	40
	7 to 11 [22 to 36]	200	90
	14 to 18 [43 to 57]	300	150
Over 0.65 to 0.75	Up to 6 [19] inclusive	300	150
	7 to 18 [22 to 57] inclusive	400	200
Over 0.75	Up to 6 [19] inclusive	300	150
	7 to 18 [22 to 57] inclusive	500	260

^a When steel reinforcing bars are to be welded to structural steel, the preheat requirements of the structural steel shall also be considered (see AWS D1.1, table titled “Prequalified Minimum Preheat and Interpass Temperature.”) The minimum preheat requirement to apply in this situation shall be the higher requirement of the two tables. However, extreme caution shall be exercised in the case of welding steel reinforcing bars to quenched and tempered steels, and such measures shall be taken as to satisfy the preheat requirements for both. If not possible, welding shall not be used to join the two base metals.

^b When the base metal is below the temperature and the size and carbon equivalent range of the bar being welded, it shall be preheated (except as otherwise provided) in such a manner that the cross section of the bar for not less than 6 in [150 mm] on each side of the joint shall be at or above the specified minimum temperature. Preheat and interpass temperatures shall be sufficient to prevent crack formation.

^c After welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited.

^d When chemical composition is not available see 1.5.4.

^e When the base metal is below 32°F [0°C], the base metal shall be preheated to at least 70°F [20°C], or above, and maintained at or above this minimum temperature during welding.

Table 7.3
Permissible Atmospheric Exposure of Low-Hydrogen Electrodes
(see 7.9.2 and 7.9.3)

<u>AWS A5 Electrode Specification</u>	Electrode	Column A (hours)	Column B (hours)
A5.1/A5.1M	E70XX	4 max	Over 4 to 10 max
	E70XXR	9 max	
	E70XXHZR	9 max	
	E7018M	9 max	
A5.5/A5.5M	E70XX-X	4 max	Over 4 to 10 max
	E80XX-X	2 max	Over 2 to 10 max
	E90XX-X	1 max	Over 1 to 5 max
	E100XX-X	1/2 max	Over 1/2 to 4 max
	E110XX-X	1/2 max	Over 1/2 to 4 max

Notes:

1. Column A: Electrodes exposed to atmosphere for longer periods than shown shall be redried before use.
2. Column B: Electrodes exposed to atmosphere for longer periods than those established by testing shall be redried before use.
3. Entire table: Electrodes shall be issued and held in quivers, or other small open containers. Heated containers are not mandatory.
4. The optional supplemental designator, R, designates a low-hydrogen electrode, which has been tested for covering moisture content after exposure to a moist environment for 9 hours and has met the maximum level permitted in AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*.

8. Qualification

8.1 General

8.1.1 Responsibility

8.1.1.1 Written WPS. All welding performed to contracts involving AWS D1.4 shall utilize written WPSs that meet the requirements of this code.

8.1.1.2 Procedure Qualification. Each contractor shall conduct the test required by Clause 8 to qualify the WPSs and the welders who will apply these WPSs.

8.1.1.3 Previous WPS Qualification. At the Engineer's discretion, evidence of previous qualification of the WPSs and welders to be employed may be accepted.

8.1.2 Welding Procedures

8.1.2.1 WPS Qualification. WPS qualification by testing in conformance with 8.2 shall be required for all joint types (see 5.2), except that WPSs for fillet welds shall be considered prequalified and exempt from testing unless performed with GTAW. All requirements of Table 8.1 shall be met for prequalified WPSs.

8.1.2.2 Engineering Approval. Subject to the approval of the Engineer, WPSs meeting the requirements of prior editions of this standard may be used.

8.1.2.3 WPS Preparation. WPS preparation shall be the responsibility of the contractor. Each WPS shall be prepared and shall include, as a minimum, the applicable essential variables of 8.2 and shall be available to those authorized to examine them. A suggested form showing the information required in the WPS is shown in Annex A.

8.1.2.4 Previous Editions. A PQR developed under a prior edition of this standard may be used to develop a WPS complying with this edition provided all the essential variables specified by this edition have been recorded.

8.1.3 Welders

8.1.3.1 Welder Qualification. Welders who perform code work shall be qualified in conformance with 8.3 prior to production welding.

8.1.3.2 WPS Welder. Welders who successfully complete a WPS qualification for either complete joint penetration groove welds or flare-groove welds shall be considered qualified for welding the type of weld joint used in the WPS qualification and other joint types as permitted in 8.3.3.1. The position of welding may be changed to the extent permitted by 8.3.4.

8.1.3.3 Previous Editions. Subject to the approval of the Engineer, welders qualified under previous editions may perform work under this edition.

8.2 WPS Qualification

8.2.1 Limitation of Variables

8.2.1.1 WPS Qualification. WPS qualification for each specification and grade of steel reinforcing bar is not required, provided that WPS parameters are within the essential variables as listed in Table 8.2.

8.2.1.2 Carbon Equivalency. WPS qualification shall be performed using a steel that has a carbon equivalent (C.E.) at least equal to the highest C.E. to be encountered in production. The WPS is then qualified for the highest C.E. value qualified and all lower values.

8.2.1.3 Coating Removal. A change from uncoated bars or steel to coated bars or steel where the coating lies within 2 in [50 mm] of weld joint preparation, or any greater distance required to prevent coating from melting and contaminating the weld metal shall require requalification. The 2 in [50 mm] limit should keep any coating from melting and contaminating the weld where the bars are in the vertical plane.

8.2.1.4 Essential Variable Change. Any changes beyond the essential variable limitations of Table 8.2 shall require WPS requalification.

8.2.2 Types of Tests and Their Purposes. The following tests are to determine the tensile strength and degree of soundness of welded joints made under a given WPS specification:

- (1) Full-section tension test (for tensile strength)
- (2) Macroetch test (for soundness)

8.2.3 Position of Test Welds. The position of production welds shall be determined from Figure 8.3 (groove) and Figure 8.4 (fillet). The test positions are defined in Figures 8.1 and 8.2. A WPS shall be required for each production welding position.

8.2.4 Test Assemblies Number, Type, and Preparation

8.2.4.1 Visual Inspection. Visual inspection shall be performed in accordance with 6.4 prior to preparing test specimens.

8.2.4.2 Number and Type of Test Assemblies. The number and type of assemblies that shall be tested to qualify a WPS are shown in Table 8.3.

8.2.4.3 Groove and T-Joint Test Assemblies. Test assemblies for groove welds in T-joints may be either direct butt joints having the same groove configuration as the T-joint to be used in construction, or the T-joint assembly shown in Figure 8.5(B).

8.2.4.4 Tension Test Assemblies. The size and length of tension test assemblies shall be as follows:

- (1) *Direct Butt Joint and T-Joint.* Unless a greater length is required for testing, welded test assemblies for direct butt joints shall be tested in accordance with Figures 8.5(A) or (B).
- (2) *Indirect Butt Joint.* For indirect butt joint welded test assemblies, the minimum length shall be at least 16 times the diameter of the bar, with the weld located centrally and shall be increased by the length of the joint [see Figures 8.5(C) and (D)]. The maximum length of the connecting welds shall be as specified in Figure 8.5(C) and (D). Note that for two bars of unequal tensile strengths, the lesser of the two values shall be used.

8.2.4.5 Macroetch Specimens. Macroetch test specimens shall be prepared as follows:

- (1) *Direct Butt Joints and T-Joints.* Each test assembly shall be mechanically cut at one location to provide a transverse cross section of each welded assembly. [See Figures 8.5(A) or (B).]
- (2) *Indirect Butt Joints.* Each test assembly shall be mechanically cut at one location to provide a transverse cross section of each welded assembly [see Figure 8.5(C) and (D)].

8.2.5 Method of Testing Specimens

8.2.5.1 Full-Section Tension Test. The minimum distance between the jaws of the testing machine shall be equal to the following:

- (1) At least eight times the diameter of the bars for direct butt joints.
- (2) At least eight times the diameter of the bar, plus the length of the joint, for indirect butt joints.

The test specimen shall be ruptured under tension load, and the maximum load shall be determined. The tensile strength shall be obtained by dividing the maximum load by the nominal cross-sectional area of the bar.

8.2.5.2 Macroetch Test. All cross sections shall be polished and etched with a suitable solution to give a clear definition of the weld.

8.2.6 Test Results Required

8.2.6.1 Full-Section Tension Test. The tensile strength shall be no less than 125% of the minimum specified yield strength of the type and grade of bars to be joined, unless otherwise specified by the contract documents.

8.2.6.2 Macroetch Test. The specimen shall be examined for discontinuities and shall meet the requirements of 6.4. For single-V or double-V-groove welds, the etched cross sections shall show complete penetration. For flare-bevel and flare-V-groove welds, the etched cross section shall show that the designated weld size has been obtained. See Figure 8.8 to determine the as-welded effective throat (E). Porosity or fusion-type discontinuities shall not exceed the limits given in Table 8.4, and the sum of all discontinuities shall not exceed 10% of the measured effective throat (E).

8.3 Welder Qualification

8.3.1 The qualification tests described here are especially devised to determine the welder's ability to produce sound welds. It is not intended that the qualification tests be used as a guide for welding during actual construction. The latter shall be performed in accordance with the requirements of the WPS.

8.3.2 Limitation of Variables

8.3.2.1 Process Qualification. Qualification with a particular process and with any of the steels permitted by this code shall be considered as qualification to weld any of the other approved steels with that process except that qualification for galvanized steel shall be performed using galvanized steel.

8.3.2.2 Qualified Bar Size Numbers. The smallest bar size number used in qualification shall qualify the welder for welding that bar size number and any larger size.

8.3.2.3 Base Metal. The base metal used shall comply with 1.5.1 or the WPS. The base metal may be uncoated or galvanized, as required by 8.3.2.1.

8.3.2.4 Electrode and Shielding Gas Combination. A welder qualified with an approved electrode and shielding medium combination shall be considered qualified to weld with any other approved electrode and shielding medium combination (see Table 7.1) for the process used in the qualification test.

8.3.2.5 Change of Position. A change in the position of welding to one for which the welder is not qualified requires qualification in that position.

8.3.3 Qualification Tests Required (See Table 8.5)

8.3.3.1 Qualification Required. Qualification tests for welders shall be as one or more of the following types of tests:

- (1) Direct butt joint groove weld test made using SMAW, GMAW, GTAW, or FCAW processes qualifies for complete joint penetration groove welds and for fillet welds.
- (2) Indirect butt joint flare-groove weld test made using SMAW, GMAW, GTAW, or FCAW processes. This test qualifies welders for welding indirect butt joints, lap joints, and for fillet welds.
- (3) Complete joint penetration groove weld T-joint made using SMAW, GMAW, GTAW, or FCAW processes qualifies welders for welding complete joint penetration groove welds (both direct butt joints and T-joints) and fillet welds.
- (4) Fillet weld tests made using SMAW, GMAW, GTAW, or FCAW processes qualifies for external fillet welds as shown in Figure 5.5(A) and (B).

8.3.3.2 Qualification Test. The qualification test assembly shall have joint details as follows:

- (1) The direct butt joint groove weld test assembly shall be a complete joint penetration groove weld made by SMAW, GMAW, GTAW, or FCAW processes [see Figure 8.6(A)]. The smallest bar size number to be fabricated shall be used.
- (2) The indirect butt joint flare-groove weld test shall be an indirect butt joint made by SMAW, GMAW, GTAW, or FCAW processes using a double-flare-bevel-groove and flat bar, as shown in Figure 8.6(C).
- (3) The complete joint penetration T-joint made by SMAW, GMAW, GTAW, or FCAW processes shall be as shown in Figure 8.6(B).
- (4) The fillet weld bend test shall be a bar welded to a plate, see Figure 8.7. The welder shall be qualified with the smallest bar size number to be used in construction. The bar shall be welded to a plate with the minimum size single pass fillet weld to be used in construction.

8.3.4 Position of Test Welds and Related Validity of Qualification

8.3.4.1 Direct Butt Joint Groove Weld Test

- (1) Qualification in the 1G (flat) position qualifies for direct butt joints in the 1G flat position, and for fillet welds in the 1F (flat) and 2F (horizontal) positions (see Figure 8.1).
- (2) Qualification in the 2G (horizontal) position qualifies for direct butt joints in the 1G (flat) and 2G (horizontal) positions and for fillet welds in 1F (flat) and 2F (horizontal) positions (see Figure 8.1).
- (3) Qualification in the 3G (vertical) position qualifies for direct butt joints in the 1G (flat), 2G (horizontal), and 3G (vertical) positions; and for fillet welds in the 1F (flat), 2F (horizontal), and 3F (vertical) positions (see Figure 8.1).
- (4) Qualification in the 4G (overhead) position qualifies for direct butt joints in the 1G (flat) and 4G (overhead) positions and for fillet welds in 1F (flat), 2F (horizontal), and 4F (overhead) positions (see Figure 8.1).

8.3.4.2 Indirect Butt Joint Flare-Groove Weld Test

- (1) Qualification in the 1G (flat) position qualifies for indirect butt joints and lap joints in the 1G (flat) position, and for fillet welds in 1F (flat), and 2F (horizontal) positions (see Figure 8.2).
- (2) Qualification in the 2G (horizontal) position qualifies for indirect butt joints and lap joints in the 1G (flat) and 2G (horizontal) positions and for fillet welds in 1F (flat), and 2F (horizontal) positions (see Figure 8.2).
- (3) Qualification in the 3G (vertical) position qualifies for indirect butt joints and lap joints in the 1G (flat), 2G (horizontal), and 3G (vertical) positions and for fillet welds in the 1F (flat), 2F (horizontal), and 3F (vertical) positions (see Figure 8.2).
- (4) Qualification in the 4G (overhead) position qualifies for indirect butt joints and lap joints in the 1G (flat) and 4G (overhead) positions and for fillet welds in 1F (flat), 2F (horizontal), and 4F (overhead) positions (see Figure 8.2).

8.3.4.3 T-Joint Groove Weld Test. The position of the groove shall govern the position qualified by the welder (see Figure 8.1).

8.3.4.4 Fillet Weld Test. The welder shall be qualified for the position tested (see Figure 8.4).

8.3.5 Test Specimens—Number, Type, and Preparation

8.3.5.1 Visual Inspection. Visual Inspection shall be performed in accordance with 6.4 prior to preparing test specimens.

8.3.5.2 Test Specimen Type and Number. The number and type of test assemblies that shall be tested to qualify a welder are shown in Table 8.5. Two test assemblies welded in accordance with 8.3.3.2 are required to qualify welders.

8.3.5.3 Direct Butt Joints. Direct butt joint welded test assemblies made by GMAW (except short circuiting transfer), GTAW, SMAW, or FCAW, shall be tested by radiography, or one test assembly shall be subjected to the full-section tension test and the other test assembly to the macroetch test. Radiography shall not be used on joints where split pipe backing is used.

8.3.5.4 Direct Butt Joints By GMAW-S. Direct butt joint welded test assemblies made by GMAW using short circuiting transfer shall have one test assembly subjected to the full-section tension test and the other to the macroetch test.

8.3.5.5 Indirect Butt Joints. Both indirect butt joint welded test assemblies shall be subjected to the macroetch test.

8.3.5.6 T-Joint Test Assembly. The two welded T-joint test assemblies shall both be subjected to the macroetch test.

8.3.5.7 Tension Test Specimens. Unless a greater length is required for testing, the full-section tension test specimen for direct butt joints shall have a minimum length of at least 16 times the diameter of the bar with the weld centrally located [see Figure 8.6(A)].

8.3.5.8 Tension Test Specimen with Split Pipe Backing. The split pipe backing need not be removed for tension testing.

8.3.5.9 Macroetch Test Specimens. Macroetch test specimens shall be prepared as follows (see Figure 8.6):

- (1) *Direct Butt and T-Joints.* [see Figure 8.6(A) or (B)].
- (2) *Indirect Butt Joint.* Each test assembly shall be cut mechanically at one location to provide a transverse cross section of each welded assembly [see Figures 8.6(C) or 8.7].

8.3.5.10 Fillet Weld Test. Test welds shall meet the visual quality requirements of 6.4.1 through 6.4.8. Two welded assemblies shall be subjected to bend testing, see 8.3.6.3.

8.3.6 Method of Testing Specimens

8.3.6.1 Full-Section Tension Test. The minimum distance between jaws of the testing machine shall be equal to at least eight times the diameter of the bar for direct butt joints. The test specimen shall be ruptured under tensile load, and the maximum load shall be determined. The tensile strength shall be obtained by dividing the maximum load by the nominal cross-sectional area of the bar.

8.3.6.2 Macroetch Test. All cross sections shall be polished and etched with a suitable solution to give a clear definition of the weld.

8.3.6.3 Fillet Weld Bend Test. Testing shall be performed after the bar is allowed to cool to ambient temperature. It shall be bent to an angle not less than 30° from its original axis. Bending may be accomplished by striking the bar with a hammer on the unwelded end or by placing a pipe or other suitable hollow device over the bar and manually or mechanically bending the bar.

8.3.7 Test Results Required

8.3.7.1 Radiographic Test. For acceptable qualification, the weld as revealed by the radiograph shall conform to the requirements of 6.4.2 and 6.4.9.

8.3.7.2 Full-Section Tension Test. The tensile strength shall not be less than 125% of the minimum specified yield strength of the type and grade of bars joined, unless otherwise stipulated by the general specification.

8.3.7.3 Macroetch Test. For direct butt joints, the etched cross sections shall show complete fusion. For flare-groove welds, the etched cross section shall show that the effective throat (E) equals or exceeds the designated weld size (see Figure 8.8). All macroetch specimens shall be examined for discontinuities and shall meet the requirements of 6.4. Porosity or fusion-type discontinuities shall not exceed the limits given in Table 8.4, and the sum of all discontinuities shall not exceed 10% of the measured effective throat (E).

8.3.7.4 Fillet Weld Bend Test Acceptance Criteria. The bar shall be bent without any separation:

- (1) Between individual weld passes,
- (2) At the fusion line between the bar and weld,
- (3) At the fusion line between the plate and weld,
- (4) In the heat-affected zone (HAZ).

Separation shall be defined as any length or width that can be seen without magnification. If a separation occurs in either of the fillet welds or heat-affected zones of the bar, the test fails. If the failure occurs within the bar, the welder shall be considered qualified.

8.4 Retests

In case a welder fails to meet the requirements of one or more test welds, a retest may be allowed under the following conditions:

8.4.1 Immediate Retest. An immediate retest may be made consisting of two welds of each type and position that the welder failed. All retest specimens shall meet all the specified requirements.

8.4.2 Retest After Further Training or Practice. A retest may be made, provided there is evidence that the welder has had further training or practice. A complete retest of the types and positions failed shall be made.

8.5 Period of Effectiveness

The welder's qualification as specified in this code shall be considered as remaining in effect indefinitely unless the welder is not engaged in a given process of welding for which the welder is qualified for a period exceeding six months, or unless there is some specific reason to question a welder's ability.

8.6 Records

Records of the test results shall be retained by the manufacturer or contractor and shall be available to those authorized to examine them.

Table 8.1
Prequalified WPS Fillet Weld Requirements (see 8.1.2.1)

Variable	Position	SMAW		GMAW/FCAW	
		in	mm	in	mm
Maximum <u>Filler Metal</u> Diameter	Flat	5/16	8	1/8	3.2
	Horizontal	1/4	6.4	1/8	3.2
	Vertical	5/32	4	3/32	2.4
	Overhead	5/32	4	5/64	2
Maximum Single Pass Fillet Weld Size	Flat	3/8	10	1/2	12
	Horizontal	5/16	8	3/8	10
	Vertical	1/2	12	1/2	12
	Overhead	5/16	8	5/16	8

Notes:

1. Fillet welds performed with GMAW-S and GTAW are not prequalified.
2. For SMAW, the maximum current shall be within the range of recommended operation by the filler metal manufacturer.

Table 8.2
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, GMAW, GTAW, and FCAW (see 8.2.1.1 and 8.2.1.4)

Essential Variable Changes to PQR Requiring Requalification	Process ^a			
	SMAW	GMAW	GTAW	FCAW
Filler Metal				
(1) Increase in filler metal classification strength, e.g., a change from E70XX to E80XX-X, but not vice versa	X	X	<u>X</u>	X
(2) A change to an electrode or method of shielding not covered in:	AWS A5.1/A5.1M or A5.5/A5.5M	AWS A5.18/A5.18M, A5.28/A5.28M, <u>A5.36/A5.36M</u>	<u>AWS</u> <u>A5.18/A5.18M</u> or <u>A5.28/A5.28M</u>	AWS A5.20/A5.20M, A5.29/A5.29M, <u>A5.36/A5.36M</u>
(3) A change in electrode diameter by:	Any increase	Any increase or decrease	—	Any increase
Electrical Parameters				
(4) A change in the amperage for each electrode diameter by:	To a value not recommended by manufacturer	>10% increase or decrease	<u>>±25% increase or decrease</u>	>10% increase or decrease
(5) A change in the voltage for each electrode diameter by:	—	>7% increase or decrease	—	>7% increase or decrease
(6) A change in type of current (AC or DC), polarity, or mode of transfer (GMAW only)	—	X	X	X
(7) A change in the travel speed by:	—	>10% increase or decrease	<u>>50% increase or decrease</u>	>10% increase or decrease
Shielding Gas				
(8) <u>A change in total gas flow rate by:</u>	—	<u>>50% increase</u> <u>>20% decrease</u>	<u>>50% increase</u> <u>>20% decrease</u>	<u>>50% increase</u> <u>>20% decrease</u>
(9) A change in shielding gas from a single gas to any other single gas or mixture of gas, or a change of more than 25% in any minor elements of the mixture, or change from a gas mixture to a single gas, or change from external shielding gas to self-shielding (i.e., no external shielding gas)	—	X	<u>X</u>	X
General				
(10) A change in the position not qualified per 8.2.3	X	X	<u>X</u>	X
(11) A change in groove type (e.g., flare-V to flare-bevel groove)	X	X	<u>X</u>	X
(12) The omission, but not inclusion, of backing material	X	X	<u>X</u>	X
(13) <u>A change in bar diameter group:</u> Group A: Bar numbers 6 and smaller Group B: Bar numbers 7 through 11 Group C: Bar numbers 14 and 18	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>

^a An “X” indicates applicability for the process; a line (—) indicates nonapplicability.

Table 8.3
Number and Type of Tests for WPS Qualification (see 8.2.4.2)

Production		Minimum Number of Test Assemblies	Tension Tests (8.2.4.4)	Macroetch Tests (8.2.4.5)	Joints Qualified per Figures
Type of Joint	Figure				
Direct butt	8.5(A)	2	2	2	5.1, 5.2, 5.5(D)
T-Joint	8.5(B)	2	2	2	5.1, 5.5(D)
Indirect butt	8.5(C)	2	2	2	5.3(A), 5.3(B), 5.4(B), 5.5(E)
Indirect butt	8.5(D)	2	2	2	5.3(C), 5.4(A)

Table 8.4
Macroetch Acceptance Criteria (see 8.2.6.2 and 8.3.7.3)

Bar Size Number	Sum of Maximum Dimensions of all Porosity or Fusion-Type Discontinuities		Maximum Dimension of Any Single Porosity or Fusion-Type Discontinuity	
	in	mm	in	mm
8 [25]	3/16	5	1/8	3
9 [29]	3/16	5	1/8	3
10 [32]	1/4	6	1/8	3
11 [36]	1/4	6	3/16	5
14 [43]	5/16	8	3/16	5
18 [57]	7/16	11	1/4	6

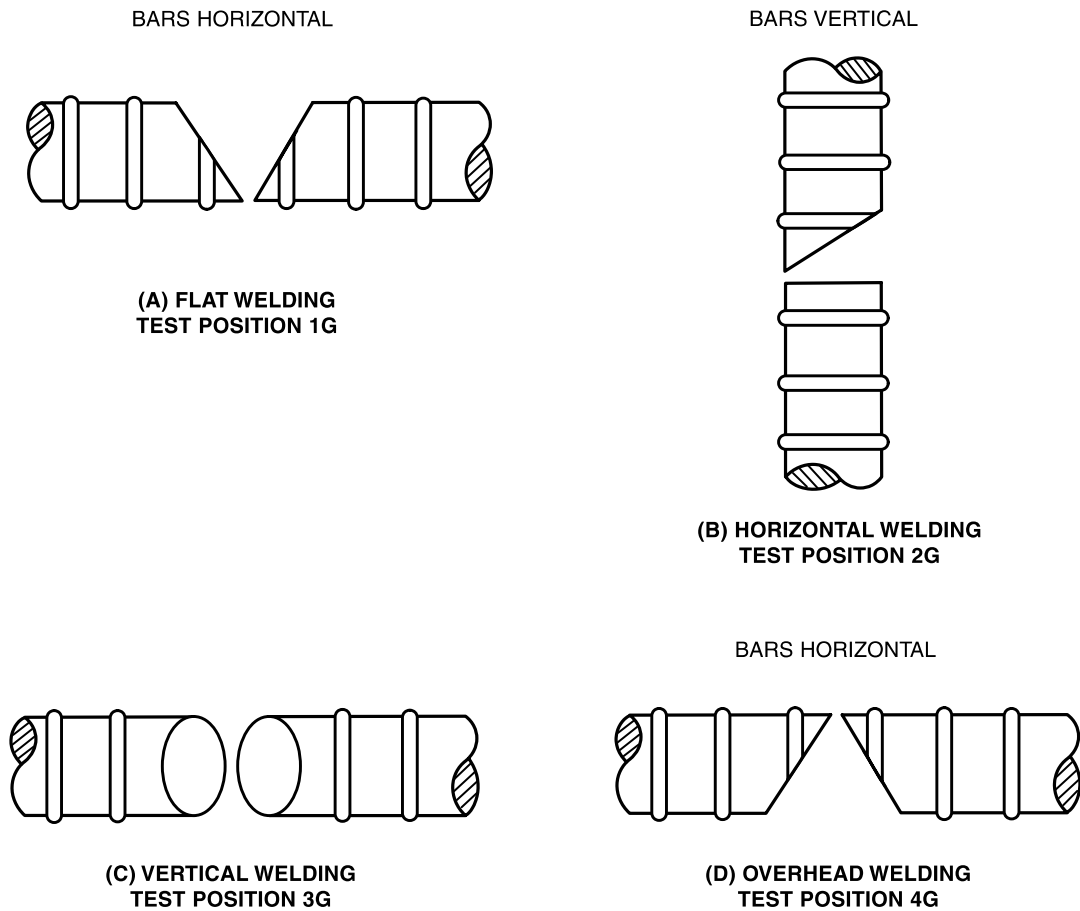
Note: Acceptance criteria for bar size numbers less than No. 8 [25] shall be established by the Engineer.

Table 8.5
Welder Qualification—Number, Types of Test, Production Welds, and Positions Qualified (see 8.3.3)

Qualification Test			Number and Type of Tests Required				Production Welding Joint and Position Qualified				
		Number of Test Assemblies Required						Direct Butt and T-Joint [Figures 5.1, 5.2, 5.5(D)]	Fillet Joint [Figure 5.5(A), (B), and (C)]	Indirect Butt Joint [Figures 5.3 and 5.5(E)]	Lap Joint (Figure 5.4)
Test Type	Test Assembly		Radiography (8.3.5.3)	Tension (8.3.5.4)	Macroetch (8.3.5.5)	Bend Test (8.3.5.10)	Test Position				
Direct Butt	Figure 8.6(A)	2	2 ^a	1 ^b	1 ^b	—	1G	F	F, H	—	—
							2G	F, H	F, H	—	—
							3G	F, H, V	F, H, O	—	—
							4G	F, OH	F, H, V	—	—
Indirect Butt	Figure 8.6(C)	2	—	—	2	—	1G	—	F, H	F, H	F, H
							2G	—	F, H	F, H	F, H
							3G	—	F, H, V	F, H, V	F, H, V
							4G	—	F, H, OH	F, OH	F, OH
T-Joint Complete Penetration	Figure 8.6(B)	2	—	—	2	—	1G	F	F, H	—	—
							2G	F, H	F, H	—	—
							3G	F, H, V	F, H, V	—	—
							4G	F, OH	F, H, OH	—	—
Fillet Weld	Figure 8.7	2	—	—	—	2	1F (Rotated)	—	F	—	—
							2F	—	F, H	—	—
							2F (Rotated)	—	F, H	—	—
							4F	—	F, H, OH	—	—
							5F	—	All	—	—

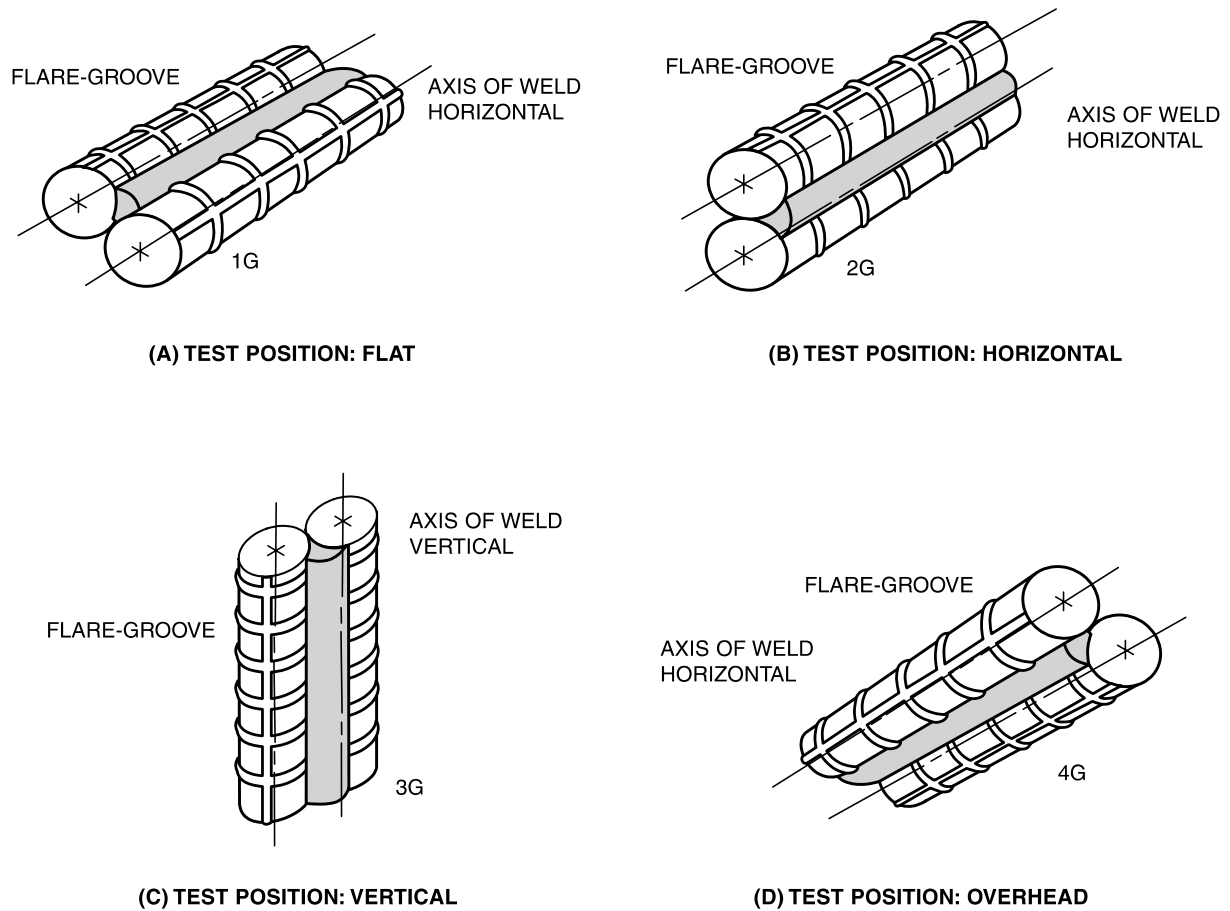
^a Radiography not permitted for welds made by GMAW short circuiting transfer.

^b Required for welds made by GMAW using short circuiting transfer. Tension and macroetch tests may be used in lieu of radiography for all other welding processes, at the Contractor's option.



Note: See Figure 8.3 for definition of positions for groove welds.

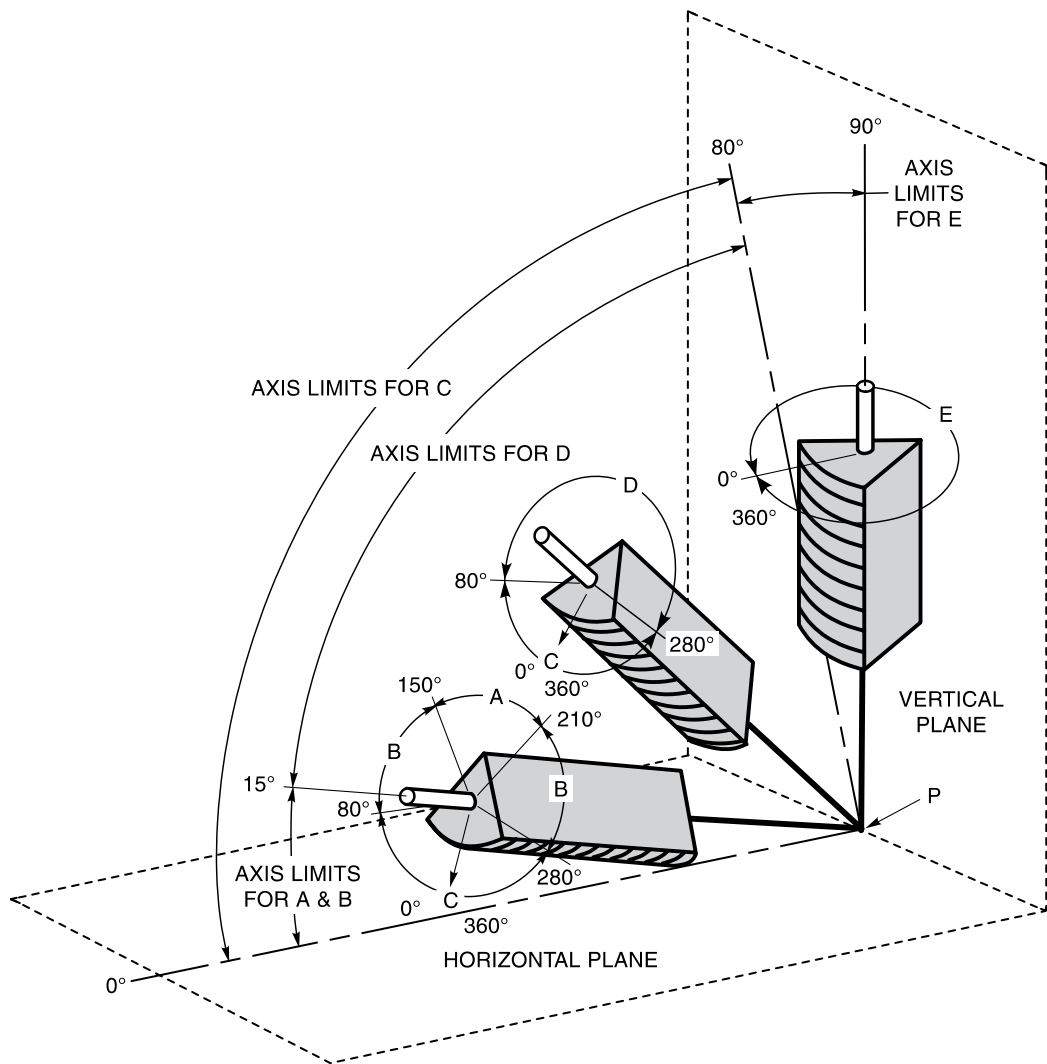
Figure 8.1—Direct Butt Joint Test Positions for Groove Welds (see 8.2.3)



Note: See Figures 8.3 and 8.4 for definitions of positions for flare-groove and fillet welds.

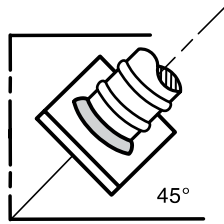
**Figure 8.2—Indirect Butt Joint Test Positions for
Flare-Groove Welds or Fillet Welds (see 8.2.3)**

Tabulation of Positions of Groove Welds			
Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	80° to 150°
			210° to 280°
Overhead	C	0° to 80°	0° to 80°
			280° to 360°
Vertical	D	15° to 80°	80° to 280°
	E	80° to 90°	0° to 360°

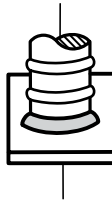


- Notes:
1. The horizontal reference plane is always taken to lie below the weld under consideration.
 2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
 3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld that passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).

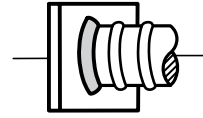
Figure 8.3—Positions of Groove Welds (see 8.2.3)



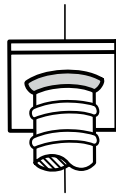
**(A) FLAT WELDING
TEST POSITION 1F
(ROTATED)**



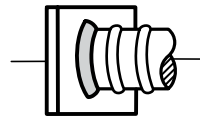
**(B) HORIZONTAL WELDING
TEST POSITION 2F
(FIXED)**



**(C) HORIZONTAL WELDING
TEST POSITION 2F
(ROTATED)**

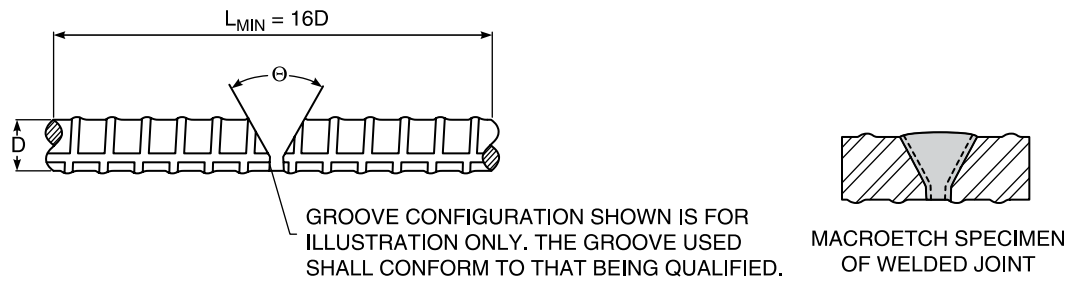
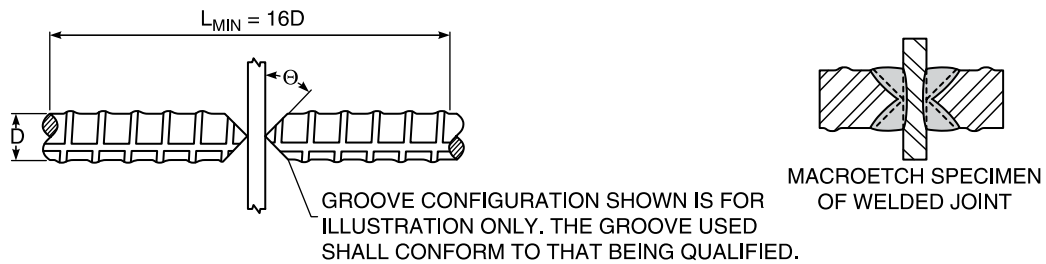
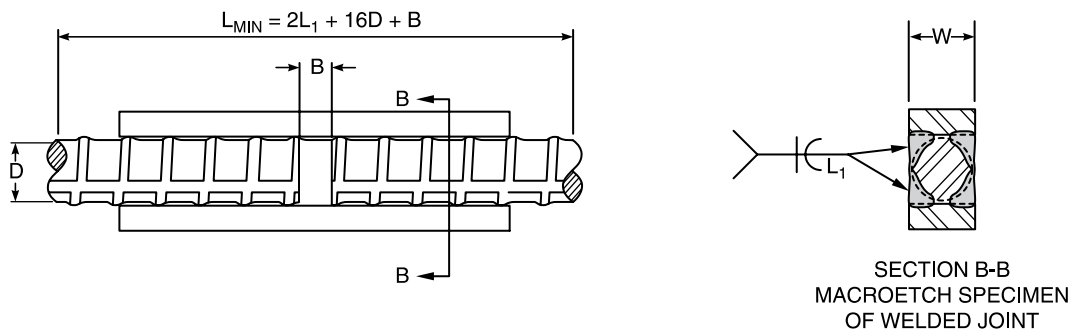


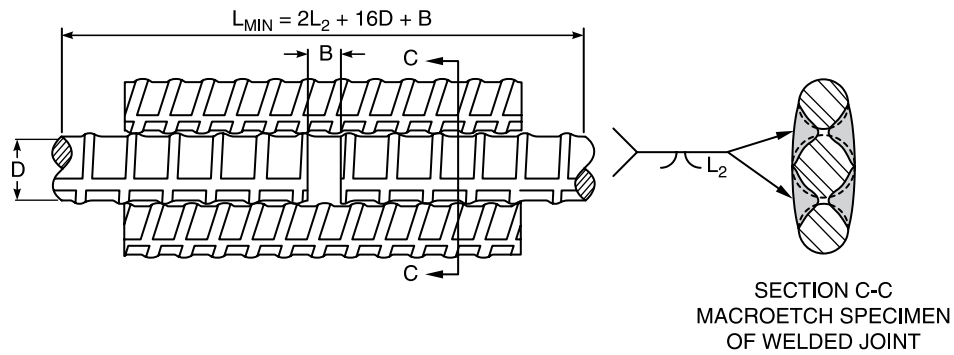
**(D) OVERHEAD WELDING
TEST POSITION 4F
(FIXED)**



**(E) MULTIPLE WELDING
TEST POSITION 5F
(FIXED)**

Figure 8.4—Positions of Fillet Welds (see 8.2.3)

**(A) COMPLETE JOINT PENETRATION GROOVE WELD – DIRECT BUTT JOINT****(B) ALTERNATIVE COMPLETE JOINT PENETRATION GROOVE WELD – T-JOINT****(C) FLARE-BEVEL-GROOVE INDIRECT BUTT-JOINT****Figure 8.5—Full-Section Test Specimens for WPS Qualification Tests (see 8.2.4.4)**

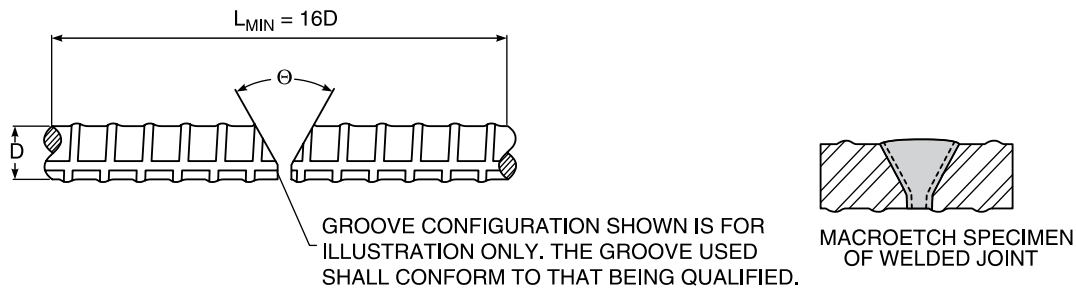


(D) FLARE-V-GROOVE INDIRECT BUTT-JOINT

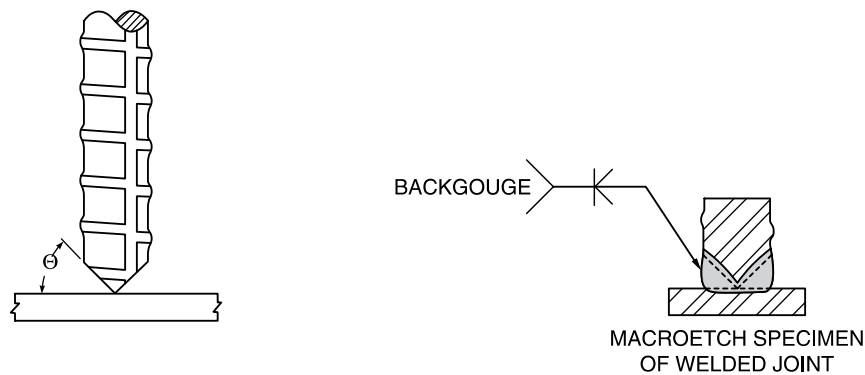
Notes:

1. B = Separation between ends of bars, maximum B = 3/4 in [19 mm]
2. $L_1 = \frac{8.18f_y(D)}{(n)F_{xx}}$ with f_y = Minimum specified yield strength of the bar (for bars of unequal f_y use lesser of the two).
 F_{xx} = Minimum specified tensile strength of weld metal.
D = Diameter of developed rebar.
n = number of connection welds between developed bar and splicing materials.
3. $L_2 = \frac{5.44F_y(D)}{(n)F_{xx}}$
4. L_1 and L_2 are maximum allowed lengths for test assemblies.
5. W = D (See 8.2.4.4)

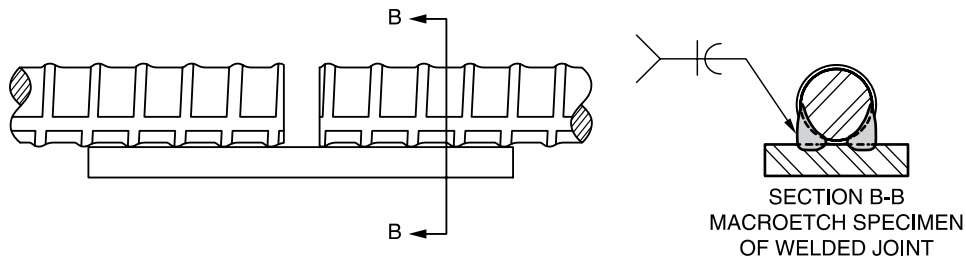
Figure 8.5 (Continued)—Full-Section Test Specimens for WPS Qualification Tests (see 8.2.4.4)



(A) COMPLETE JOINT PENETRATION GROOVE WELD – DIRECT BUTT-JOINT



(B) COMPLETE JOINT PENETRATION GROOVE WELD – T-JOINT



(C) FLARE-BEVEL-GROOVE INDIRECT BUTT-JOINT

^a B = Separation between ends of bars. Maximum: B = 3/4 in [19 mm].

Notes:

1. For Bar sizes No. 9 [29] or larger, use single-V or single-bevel-groove welds. See Figure 5.2(A) or (D).
2. For Bar sizes No. 8 [25] or smaller, use single-V with split pipe backing. See Figure 5.2(C).

Figure 8.6—Full-Section Tension Test and Macroetch Test Specimens for Welder Qualification Tests (see 8.3.3.2)

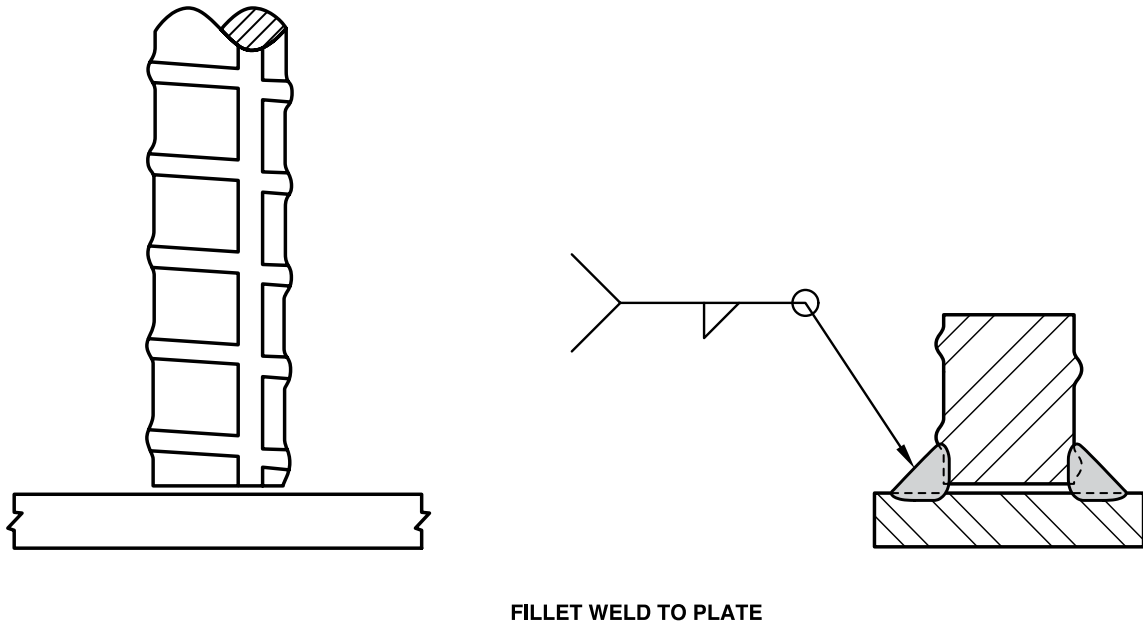
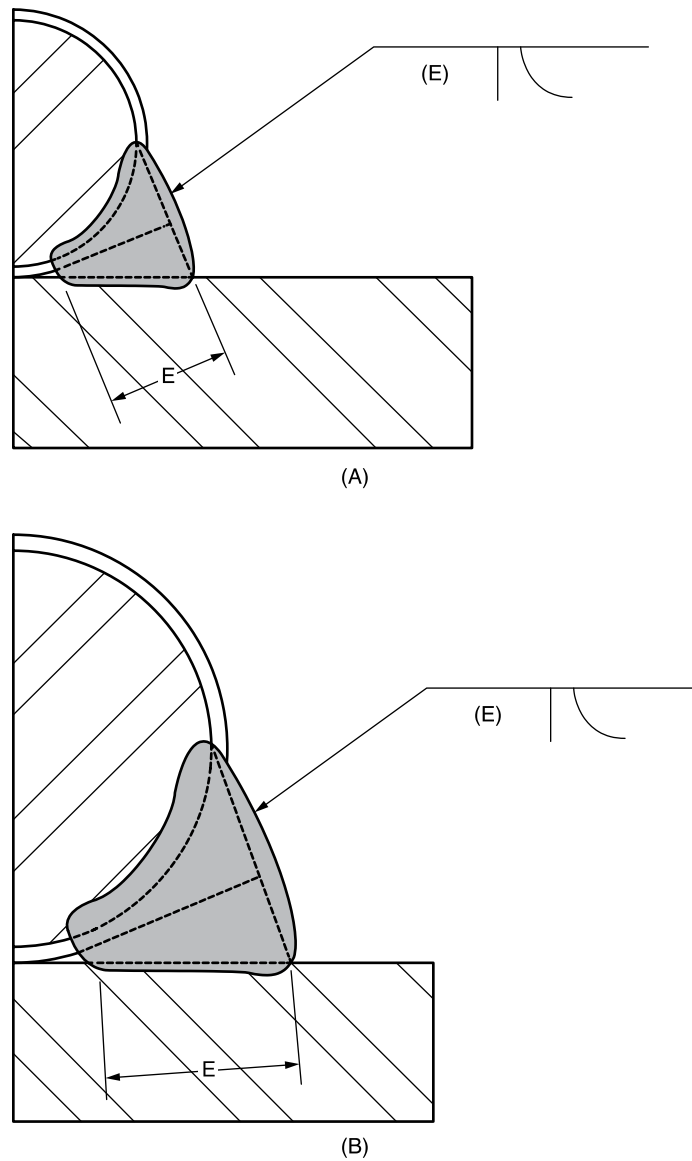


Figure 8.7—Bend Test Specimen for Welder Qualification Tests (see 8.3.3.2)



Note: Throat shall be measured as the shortest distance from the theoretical face to the point of fusion at the root as shown in dimension (E).

Figure 8.8—Flare-Bevel Groove Weld Effective Throat (see 8.2.6.2 or 8.3.7.3)

9. Inspection

9.1 General Conditions

9.1.1 Inspector Duties. The inspector shall verify that fabrication by welding is performed in accordance with the requirements of this code.

9.1.2 Inspector Qualification. Inspectors responsible for acceptance or rejection of material and workmanship shall be qualified. The basis of Inspector qualification shall be documented. If the Engineer elects to specify the basis of inspector qualification, it shall be so stated in contract documents.

The following are acceptable qualification bases:

(1) Current or previous certification as an AWS Certified Welding Inspector (CWI) in accordance with the provisions of AWS QC1, *Standard for AWS Certification of Welding Inspectors*;

(2) Current or previous qualification by the Canadian Welding Bureau (CWB) to the requirements of the Canadian Standard Association (CSA) Standard W178.2, *Certification of Welding Inspectors*;

(3) An individual who, by training or experience, or both, in metals fabrication, inspection and testing, is competent to perform inspection of the work.

9.1.3 Detail Drawings. The Inspector shall be furnished with complete detail drawings showing the size, length, type, and location of all welds to be made.

9.1.4 Inspector Notification. The Inspector shall be notified, in advance, of the start of any welding operations.

9.2 Inspection of Base Metals

The inspector shall verify that only base metals are used that conform to the requirements of this code.

9.3 Inspection of WPS Qualification and Equipment

The Inspector shall verify the welding and subsequent testing of any WPS qualification specimens that are required.

The Inspector shall inspect the welding equipment to be used for the work to verify that it is in such condition as to enable qualified welders to apply qualified WPSs and attain results prescribed elsewhere in this code.

9.4 Inspection of Welder Qualifications

9.4.1 The Inspector shall permit welding to be performed only by welders who are qualified in accordance with the requirements of this code. The Inspector shall witness the welding and testing of qualification specimens for each welder, or shall make certain that each welder has previously demonstrated those qualifications under other acceptable supervision.

9.4.2 Welder Requalification. When the quality of the welder's work appears to be below the requirements of this code, the Inspector may require testing of a welder's qualification by means of partial or complete requalification in accordance with 8.3.

9.5 Inspection of Work and Records

9.5.1 Inspection of Welds. The Inspector shall verify that the size, length, and location of all welds conform to the requirements of this code and to the detail drawings, that no specified welds are omitted, and that no unspecified welds have been added without approval.

9.5.2 Inspection of WPS. The Inspector shall verify that the WPSs used meet the provisions of this code.

9.5.3 Conformance to WPS. The Inspector shall verify that welders have copies of, or access to, the WPSs, and that the welding is performed in conformance with the WPS and code requirements.

9.5.4 Observation of Welding. The Inspector shall, at suitable intervals, observe the technique and performance of each welder to verify that the applicable requirements of this code are met.

9.5.5 Examination of Work. The Inspector shall examine the work to verify that it meets the requirements of this code. Size and length of welds shall be measured with suitable gages. Visual inspection for cracks and other discontinuities in the welds and base metal should be aided by a strong light, magnifiers, or other helpful devices as necessary.

9.5.6 Marking Inspections. Inspectors shall identify with a distinguishing mark or other recording methods all parts or joints that they have inspected and accepted. Any recording method that is mutually agreeable may be used. Die stamping of cyclically loaded members is not permitted without the approval of the Engineer.

9.5.7 Inspection Record Keeping. The Inspector shall keep a record of qualifications of all welders, all WPS qualifications, or other tests that are made.

9.6 Obligations of the Contractor

9.6.1 Contractor Welding Inspection. The Contractor shall be responsible for visual inspection and necessary correction of all deficiencies in materials and workmanship in accordance with the requirements of Clauses 5 and 6, and 6.4 or other parts of this code, as applicable.

9.6.2 Inspector Requests. The contractor shall comply with all requests of the Inspector(s) to correct deficiencies in materials and workmanship as provided in the contract documents.

9.6.3 Damaged Base Metal. In the event that faulty welding or its removal for rewelding damages the base metal so that in the judgment of the Engineer its retention is not in accordance with the intent of the contract documents, the Contractor shall remove and replace the damaged base metal or shall compensate for the deficiency in a manner approved by the Engineer.

9.6.4 Nondestructive Testing. When nondestructive testing other than visual inspection is specified in the information furnished to bidders, it shall be the Contractor's responsibility to ensure that all specified welds meet the quality requirement of 6.4.

9.6.5 Nonspecified Nondestructive Testing. If nondestructive testing other than visual inspection is not specified in the original contract agreement but is subsequently requested by the Owner, the Contractor shall perform any requested testing or shall permit any testing to be performed in accordance with 9.7. The Owner shall be responsible for all associated costs including handling, surface preparation, nondestructive testing, and repair of discontinuities other than those listed in 6.4.1 to 6.4.8 inclusive, at rates mutually agreeable between Owner and Contractor. However, if such testing should disclose an attempt to defraud or gross nonconformance to this code, repair work shall be done at the Contractor's expense.

9.7 Nondestructive Testing

9.7.1 Specification for Nondestructive Testing. When nondestructive testing other than visual is required, it shall be so stated in the information furnished to the bidders. This information shall designate the welds to be examined, the extent of the examination of each weld, and method of testing.

9.7.2 Repair of Welds. Welds tested nondestructively that do not meet the requirements of this code shall be repaired using the applicable provisions of this code.

9.7.3 Radiographic Testing. When radiographic testing is used, the procedure and technique shall be in accordance with 9.9.

9.7.4 Magnetic Particle Testing. When magnetic particle testing is used, the procedure and technique shall be in accordance with ASTM E709, *Standard Guide for Magnetic Particle Examination*, and the standard of acceptance shall be in accordance with 6.4 of this code.

9.7.5 Liquid Penetrant Testing. For detecting discontinuities that are open to the surface, liquid penetrant inspection may be used. The standard methods set forth in ASTM E165, *Standard Test Method for Liquid Penetrant Inspection*, shall be used for liquid penetrant inspection, and the standards of acceptance shall be in accordance with 6.4 of this code.

9.7.6 Ultrasonic Testing. Ultrasonic inspection of direct butt joints in deformed steel reinforcing bars is not considered feasible except by highly specialized techniques and is not recommended.

9.8 Personnel Qualification

9.8.1 ASNT Requirements. Personnel performing NDT other than visual shall be qualified in conformance with the current edition of the American Society for Nondestructive Testing *Recommended Practice No. SNT-TC-1A*. Individuals who perform NDT shall be qualified for:

- (1) NDT Level II, or
- (2) NDT Level I working under the NDT Level II

9.9 Radiographic Testing

9.9.1 Radiographic Testing of Direct Butt Joints

9.9.1.1 Weld Quality. Prior to radiographic testing, welds shall meet the visual criteria described in 6.4. When radiographic testing of direct butt joints is required, the maximum dimension of any single porosity or fusion-type discontinuity, or the sum of the maximum dimensions of all porosity and fusion-type discontinuities, shall not exceed the limits given in Table 6.1. Welds tested nondestructively that do not meet the requirements of this code shall be repaired using the applicable provisions of this code.

9.9.2 Radiographic Procedures

9.9.2.1 Procedure. Radiographs shall be made using a single source of either X-ray or gamma-ray radiation. The radiographic sensitivity shall be judged based on hole-type image quality indicators (IQI). Radiographic technique and equipment shall provide sufficient sensitivity to clearly delineate the required hole-type IQIs and the essential holes as described in IQI Selection and Placement, Table 9.1, and Figure 9.1. Identifying letters and numbers shall show clearly in the radiograph.

The methodology shall conform to ASTM E94, *Standard Guide for Radiographic Testing*, and ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*.

9.9.2.2 Safety Requirements. Radiography shall be performed in accordance with all applicable safety requirements.

9.9.2.3 Weld Reinforcement. Weld reinforcement shall not exceed the provisions given in Figure 6.2. Weld surfaces need not be ground or otherwise smoothed for purposes of radiographic testing unless surface irregularities or the junction between weld and base metal exist that may cause weld discontinuities to be obscured in the radiograph.

9.9.2.4 Tabs. Weld tabs shall be removed prior to radiographic inspection.

9.9.2.5 Steel Backing. When required by the contract documents, steel backing shall be removed, and the surface shall be finished flush by grinding prior to radiography.

9.9.2.6 Reinforcement. When weld reinforcement or backing, or both, is not removed, steel shims that extend at least 1/8 in [3 mm] beyond three sides of the required IQI shall be placed under the hole-type IQI. The total thickness of steel between the IQI and the film is approximately equal to the average thickness of the weld measured through its reinforcement and backing.

9.9.2.7 Radiographic Film. Radiographic film shall be as described in ASTM E94. Lead foil screens shall be used as described in ASTM E94. Fluorescent screens shall not be permitted.

9.9.2.8 Technique. Radiographs shall be made with a single source of radiation centered as near as practicable with respect to the centerline of the weld and width of the bar. The source shall be positioned so that the inspecting radiation passes through the plane of the weld at an angle normal to the long axis of the bar. No inspecting radiation shall penetrate any portion of the weld represented in the radiograph at an angle greater than $26\text{-}1/2^\circ$ from a line normal to the weld surface. See Figure 9.1 for source position.

9.9.2.9 Two Direction Radiography. Two exposures shall be made for each direct butt joint tested. The first exposure shall be made with the radiation source placed at 0° from the top of the weld and exactly perpendicular to the weld root or backing bar and identified with a lead station mark of “0.” The second exposure shall be at 90° to the “0” station mark and shall be identified with a lead station mark “90.” When obstructions prevent an exact 90° placement of the radiation source, for the second exposure, the source may be rotated around the centerline of the steel reinforcing bar weld $\pm 35^\circ$ from 90° and identified with a lead station mark appropriate to the location. Deviation from 0° and 90° positions shall require approval of the Engineer.

9.9.2.10 Backing Bar Width. The width of the backing bar shall not project beyond the diameter of the steel reinforcing bar in order to facilitate the perpendicular placement of the film in relation to the source of the 90° exposure.

9.9.2.11 Backing Bar Length. The length of the backing bar shall be sufficient to extend past the radiographic area of interest and allow for placement of the IQI within the radiographic image of the backing bar.

9.9.2.12 Film Placement. The radiographic film shall be placed perpendicular to the radiation source at all times and in contact with the steel reinforcing bar. The film shall be placed at the root of the joint for the 0° exposure. See Figure 9.2 for film placement.

9.9.2.13 Geometric Unsharpness. Gamma-ray sources, regardless of size, shall be capable of meeting the geometric unsharpness limitation of ASME *Boiler and Pressure Vessel Code*, Section V, Article 2, regardless of the size of the steel reinforcing bar.

9.9.2.14 Source-to-Subject Distance. The source-to-subject distance shall be maintained so as to not violate the maximum geometric unsharpness criteria of 0.020, at all times, as specified in ASME *Boiler and Pressure Vessel Code*, Section V, Article 2. The source-to-subject distance shall not be less than seven times the thickness of weld plus reinforcement and backing, if any.

9.9.2.15 Sources. X-ray units, 600 kvp maximum, and iridium 192 may be used as a source for all radiographic inspection provided they have adequate penetrating ability. Other radiographic sources shall be subject to the approval of the Engineer.

9.9.2.16 IQI Selection and Placement. Hole-type IQIs shall be selected and placed on the source side of the bar, perpendicular to the radiation source and nearest the area of interest being radiographed. One hole-type IQI shall be placed in the center of each bar to be radiographed with the 2T hole being closest to the weld and the IQI identification numbers being furthest from the weld. IQI image shall not appear in the radiographic image of the weld. When more than one bar is being radiographed each shall have an IQI placed as described above. Wire penetrameters or penetrometer blocks shall not be used. Penetrometer image density shall be maintained in accordance with the density limitations specified for the area of interest.

9.9.2.17 Technique Coverage. Welded joints shall be radiographed by methods that will provide complete inspection of the joint within the limits specified to be examined. Short film, short screens, excessive undercut by scattered radiation, or any other process that obscures portions of the total weld shall render the radiograph unacceptable.

9.9.2.18 Film Length. Film shall have sufficient length and shall be placed to provide at least 1/2 in [12 mm] of film beyond the projected edge of the weld.

9.9.2.19 Film Width. Film widths shall be sufficient to depict all portions of the weld joint, including the heat-affected zones (HAZs), and shall provide sufficient additional space for the required hole-type IQIs and film identification without infringing upon the areas of interest in the radiograph.

9.9.2.20 Backscatter. To check for backscatter radiation, a lead symbol “B,” 1/2 in [12 mm] high, 1/16 in [2 mm] thick shall be attached to the back of each film cassette. If the “B” image appears on the radiograph, the radiograph shall be considered unacceptable. A dark image of the “B” on a lighter background is not cause for rejection.

9.9.2.21 Quality of Radiograph. All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they cannot mask or be confused with the image of any discontinuity in the area of interest in the radiograph. Such blemishes include, but are not limited to, the following:

- (1) fogging
- (2) processing defects such as streaks, water marks, or chemical stains
- (3) scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears
- (4) loss of detail due to poor screen-to-film contact
- (5) false indications due to defective screens or internal faults

9.9.2.22 Density Limitations. The transmitted film density through the radiographic image of the body of the required hole-type IQI(s) and the area of interest shall be 1.8 minimum for single film viewing for radiographs made with an X-ray source and 2.0 minimum for radiographs made with a gamma-ray source. For composite viewing of double film exposures, the minimum density shall be 2.6. Each radiograph of a composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing.

9.9.2.23 Transitions. When welds between bars with differing diameters are radiographed and the ratio of the thickness of the thicker section to the thickness of the thinner section is 3 or greater, radiographs should be exposed to produce single film densities of 3.0 to 4.0 in the thinner section. When this is done, the minimum density requirements stated above shall be waived unless otherwise provided in the contract documents.

9.9.2.24 Double Loaded Cassettes. Due to the geometric condition of steel reinforcing bars, the use of double loaded cassettes with film of differing speeds may be required in order to maintain proper density throughout the full cross-sectional area thickness of the bar. Variations in density between double loaded film shall be maintained by film speed and exposure time and not by reducing or increasing the development time beyond the film manufacturer’s recommended development duration. When utilizing double loaded cassettes, the radiographic film density shall comply with the requirements for single film viewing in the area represented by the film. The middle portions or through thickness of the bar shall be represented by one film that has a faster exposure speed and the outer radius portion of the bar shall be represented by a second film that has a slower exposure speed. Each film is viewed separately and the evaluations are combined to determine the disposition of the weld in accordance with Table 6.1.

9.9.2.25 H & D Density. The density measured shall be H & D density (radiographic density), which is a measure of film blackening, expressed as follows:

$$D = \log I_o/I \quad \text{where} \quad D = H \text{ \& D (radiographic) density}$$

$$I_o = \text{light intensity on the film, and}$$

$$I = \text{light transmitted through the film.}$$

9.9.2.26 Identification Marks. A radiograph identification mark and station identification marks shall be placed on the bar at each radiograph location. A corresponding radiograph identification mark and station identification marks, all of which shall show in the radiograph, shall be produced by placing lead numbers or letters, or both, over each of the identical identification and location marks made on the steel to provide a means for matching the developed radiograph to the weld. Additional identification information may be preprinted no less than 3/4 in [20 mm] from the edge of the weld or shall be produced on the radiograph by placing lead figures on the steel. Information required to show on the radiograph shall include the contract identification, initials of the radiographic inspection company, initials of the fabricator, the fabricator shop order number, the radiographic identification mark, the date, and the weld repair number, if applicable. Each piece of film identification information shall be clearly legible. Film shall be identified by lead letters or numbers.

9.9.3 Examination, Report, and Disposition of Radiographs

9.9.3.1 Equipment Provided by Contractor. The Contractor shall provide a suitable variable intensity illuminator (viewer) with spot review or masked spot review capability. The viewer shall incorporate a means for adjusting the size

of the spot under examination. The viewer shall have sufficient capacity to properly illuminate radiographs with an H & D density of 4.0. Film review shall be done in an area of subdued light.

9.9.3.2 Reports. Before a weld subject to radiographic testing is accepted, all of its radiographs, including any that show unacceptable quality prior to repair, and a report interpreting them shall be submitted to the Engineer.

9.9.3.3 Record Retention. A full set of radiographs for welds subject to radiographic testing by the Contractor for the Owner, including any that show unacceptable quality prior to repair, shall be delivered to the Owner upon completion of the work. The Contractor's obligation to retain radiographs shall cease (1) upon delivery of this full set to the Owner, or (2) one full year after the completion of the Contractor's work, provided the Owner is given prior written notice.

9.9.3.4 Radiograph Interpretation. All radiographs shall be interpreted by an individual certified as a Level II in accordance with the latest edition of the American Society for Nondestructive Testing's *Recommended Practice No. SNT-TC-1A*. Interpretation of direct butt joints in steel reinforcing bars is considerably more difficult than interpreting groove welds in butt joints between plates. Individuals responsible for interpreting steel reinforcing bar weld radiographs shall be experienced in the radiographic techniques required to evaluate the complex geometric characteristics of cylindrical objects.

Table 9.1
Hole-Type Image Quality Indicator (IQI) Requirements (see 9.9.2.1)

Bar Size Number		Source Side (IQI)	
<u>U.S. Customary</u>	<u>SI Units</u>	<u>Designation</u>	<u>Essential Hole</u>
3	10	12	4T
4	13	15	4T
5	16	15	4T
6	19	17	4T
7	22	20	4T
8	25	20	4T
9	29	25	4T
10	32	30	2T
11	36	30	2T
14	43	35	2T
18	57	40	2T

Notes:

1. Weld reinforcement has been accounted for in the above table.
2. No increase in IQI designation or change in essential hole is permitted to account for weld reinforcement or backing.
3. Film side IQIs are prohibited.

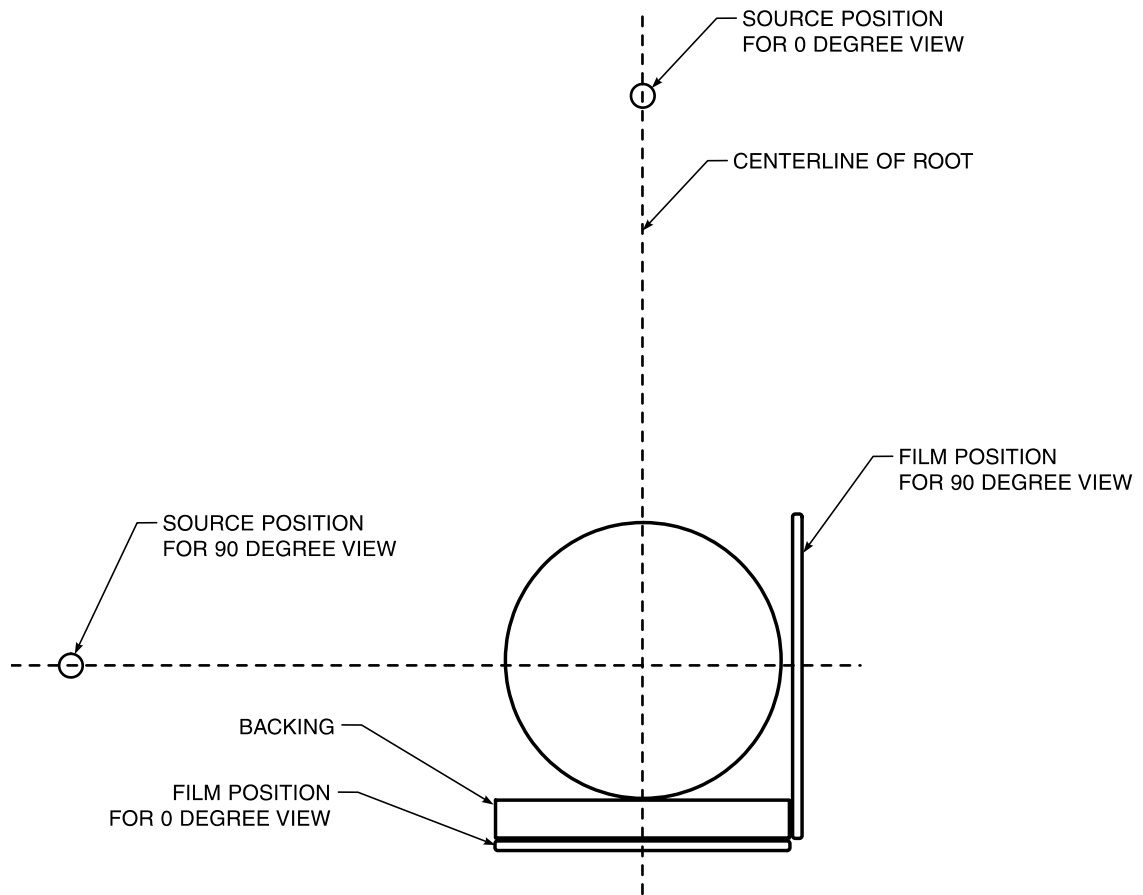


Figure 9.1—Source Position (see 9.9.2.1)

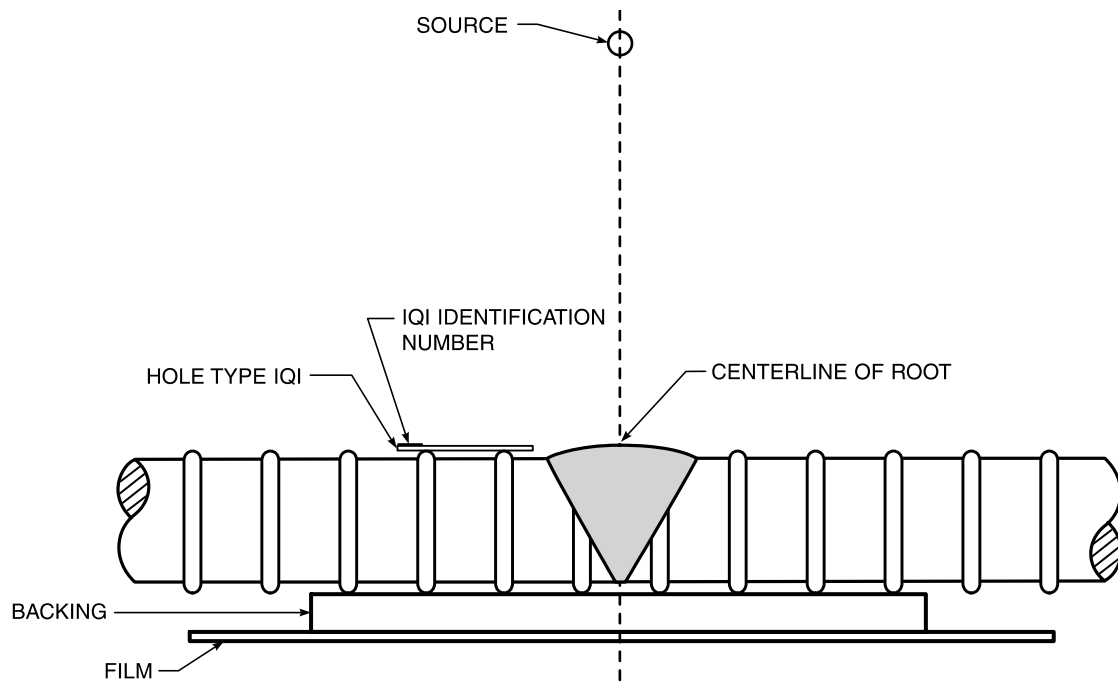


Figure 9.2—Film Placement (see 9.9.2.12)

Annex A (Informative)

Sample Welding Forms

This annex is not part of this standard but is included for informational purposes only.

This annex contains three sample forms:

Form A-1: Sample Procedure Qualification Record (PQR) Form

Form A-2: Sample Welding Procedure Specification (WPS) Form

Form A-3: Sample Welder Qualification Test Record

Sample Procedure Qualification Record (PQR) Form

Procedure Qualification Record (PQR) No. _____

Contractor _____

Authorized by _____

Revision No. _____

Welder _____

Test Date _____

Welding Process: ☐ FCAW-G ☐ FCAW-S ☐ GMAW ☐ SMAW ☐ GTAW

PQR JOINT TYPE

☐ Direct Butt ☐ Indirect Butt ☐ T-Joint

Test Assembly: ☐ Figure 8.5(A) ☐ Figure 8.5(B) ☐ Figure 8.5(C)

Position _____

Groove Type _____

☐ Single Bevel ☐ Double Bevel

Root Opening _____

Root Face _____

Groove Angle _____

Backing: ☐ Yes ☐ No

Backing Type _____

Backgouging: ☐ Yes ☐ No

Backgouging Method _____

Technique: ☐ Stringers ☐ Weave

ELECTRICAL CHARACTERISTICS

Current: ☐ AC ☐ DCEP ☐ DCEN

Transfer Mode (GMAW): ☐ Short circuiting ☐ Globular ☐ Spray

BASE METAL

Material Specification _____ Grade _____

welded to

Material Specification _____ Grade _____

Carbon Equivalent (Bar) _____

Bar size _____

Coated Bar: ☐ Yes ☐ No

Type of Coating _____

FILLER METAL

AWS Specification _____ AWS Classification _____

Describe filler metal (if not covered by AWS specification) _____

SHIELDING

Gas: ☐ Single ☐ Mixture

Composition _____ Flow rate _____

PREHEAT/INTERPASS

Preheat/Interpass Temperature (Min) _____

Interpass Temperature (Max) _____

WELDING PARAMETERS

Pass Number	Electrode Diameter	Current					Travel Speed (ipm)	Joint Detail
		Type	Amperage	WFS ipm [mm/min.]	Volts	Electrical Stickout		

Note: Attach additional sheets as required for detailing each pass.

Form A-1 (front)

Sample Procedure Qualification Record (PQR) Form

Continuation of Procedure Qualification Record (PQR) No. _____

TEST RESULTS

VISUAL EXAMINATION

Test Assembly Number One

☐ Pass ☐ Fail (AWS D1.4, Subclause 6.4)

Comments _____

Test Assembly Number Two

☐ Pass ☐ Fail (AWS D1.4, Subclause 6.4)

Comments _____

TENSILE TEST

Test Assembly Number One

☐ Pass ☐ Fail (AWS D1.4, Subclause 8.3.7.2)

Test Assembly Number Two

☐ Pass ☐ Fail (AWS D1.4, Subclause 8.3.7.2)

Specimen No.	Width	Thickness	Area	Ultimate Tensile Load (lbs)	Ultimate Unit Stress (psi)	Character of Failure and Location

MACROETCH TEST

Test Assembly Number One

☐ Pass ☐ Fail (AWS D1.4, Subclause 8.3.7.3)

Test Assembly Number Two

☐ Pass ☐ Fail (AWS D1.4, Subclause 8.3.7.3)

Specimen No.	Results	Remarks

Welder's Name _____

Clock No. _____ Stamp No. _____

Test conducted by _____ (Laboratory)

Test Number _____

Per _____

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of AWS D1.4/D1.4M:2018, *Structural Welding Code—Steel Reinforcing Bars*.

Manufacturer or Contractor _____

Authorized by _____

Date _____

Sample Welding Procedure Specification (WPS) Form

Welding Procedure Specification (WPS) No. _____

Contractor _____

Authorized by _____

Revision No. _____

Supporting PQR Identification _____

Test Date _____

WELDING PROCESS: ☐ FCAW-S ☐ FCAW-G ☐ GMAW ☐ SMAW ☐ GTAW

WELD TYPE: ☐ Groove ☐ Fillet

JOINT TYPE: ☐ Direct Butt ☐ Indirect Butt ☐ T-Joint

Joint(s) Qualified (see Table 8.3) _____

Position _____ Groove Type _____

Root Opening _____ Root Face _____ Groove Angle _____

Backing: ☐ Yes ☐ No Backing Type _____

Backgouging: ☐ Yes ☐ No Backgouging Method _____

TECHNIQUE: ☐ Stringers ☐ Weave

ELECTRICAL CHARACTERISTICS

Current: ☐ AC ☐ DCEP ☐ DCEN

Transfer Mode (GMAW): ☐ Short-circuiting ☐ Globular ☐ Spray

BASE METAL

Material Specification _____ Grade _____

Welded to: Material Specification _____ Grade _____

Maximum Carbon Equivalent _____ Bar size _____ Plate Thickness _____

Coated Bar: ☐ Yes ☐ No Type of Coating _____

FILLER METAL

AWS Specification _____ AWS Classification _____

Describe filler metal (if not covered by AWS specifications) _____

SHIELDING

Gas: ☐ Single ☐ Mixture Composition _____ Flow rate _____

PREHEAT/INTERPASS

Preheat/Interpass Temperature (Min) _____ Interpass Temperature (Max) _____

WELDING PARAMETERS

Pass Number(s)	Electrode Diameter	Current				Travel Speed ipm [mm/min.]	Joint Detail
		Type	Amperage Range	Volts Range	Electrical Stickout		

Manufacturer or Contractor _____

Authorized by _____ Date _____

Sample Welder Qualification Test Record

Welder's Name & ID No. _____

Date _____

Welding Procedure Specification No. _____

Revision No. _____

Process: ☐ GMAW ☐ FCAW ☐ GTAW ☐ SMAW ☐ GMAW-S	Material Specification: Bar _____ Structural Steel _____	☐ T-Joint [Figure 8.5(B)] ☐ Direct Butt [Figure 8.5(A)] ☐ Indirect Butt [Figure 8.5(D)] ☐ Fillet [Figure 8.7]
Backing: ☐ Yes ☐ No	Position: ☐ Vertical Up ☐ OH ☐ Horizontal ☐ Flat	Material Specification: Bar to Bar _____ Bar to Structural Steel _____

FILLER METAL

AWS Specification No. _____	AWS Classification _____
Electrode _____	Diameter/F No. _____
Shielding Gas _____	Trade Name _____

TEST RESULTS

Visual Weld Appearance: (Subclause 6.4) 1. ☐ Pass ☐ Fail 2. ☐ Pass ☐ Fail	Tensile Strength, psi: (Subclause 8.3.7.2) 1. _____ 2. _____
Macroetch Test Results: (Subclause 8.3.7.3) 1. ☐ Pass ☐ Fail 2. ☐ Pass ☐ Fail	Fillet Weld Test: (Subclause 8.3.7.4) 1. ☐ Pass ☐ Fail 2. ☐ Pass ☐ Fail
Interpreted by _____ Organization _____	Test No. _____ Date _____

RADIOGRAPHIC TEST RESULTS

Film Identification	Results	Remarks	Film Identification	Results	Remarks

Interpreted by _____	Test No. _____
Organization _____	Date _____

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of AWS D1.4/D1.4M:2018, *Structural Welding Code—Steel Reinforcing Bars*.

Manufacturer or Contractor _____

Authorized by _____

Date _____

QUALIFICATION RESULTS

The Welder/Operator identified above ☐ DOES ☐ DOES NOT meet the performance qualifications specified in the AWS D1.4/D1.4M:2018 code for the variables stated.
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Annex B (Informative)

Nominal Dimensions of ASTM Standard Reinforcing Bars

This annex is not part of this standard but is included for informational purposes only.

Bar Size Number ^{a,b}		Unit Weight		Diameter		Cross-Sectional Area	
U.S. Customary	SI Units	lb/ft	kg/m	in	mm	in ²	mm ²
3	10	0.376	0.56	0.375	9.5	0.11	71
4	13	0.668	0.994	0.500	12.7	0.20	129
5	16	1.043	1.55	0.625	15.9	0.31	199
6	19	1.502	2.24	0.750	19.1	0.44	284
7	22	2.044	3.042	0.875	22.2	0.60	387
8	25	2.670	3.973	1.000	25.4	0.79	510
9	29	3.400	5.060	1.128	28.7	1.00	645
10	32	4.303	6.404	1.270	32.3	1.27	819
11	36	5.313	7.909	1.410	35.8	1.56	1006
14	43	7.650	11.38	1.693	43.0	2.25	1451
18	57	13.60	20.24	2.257	57.3	4.00	258

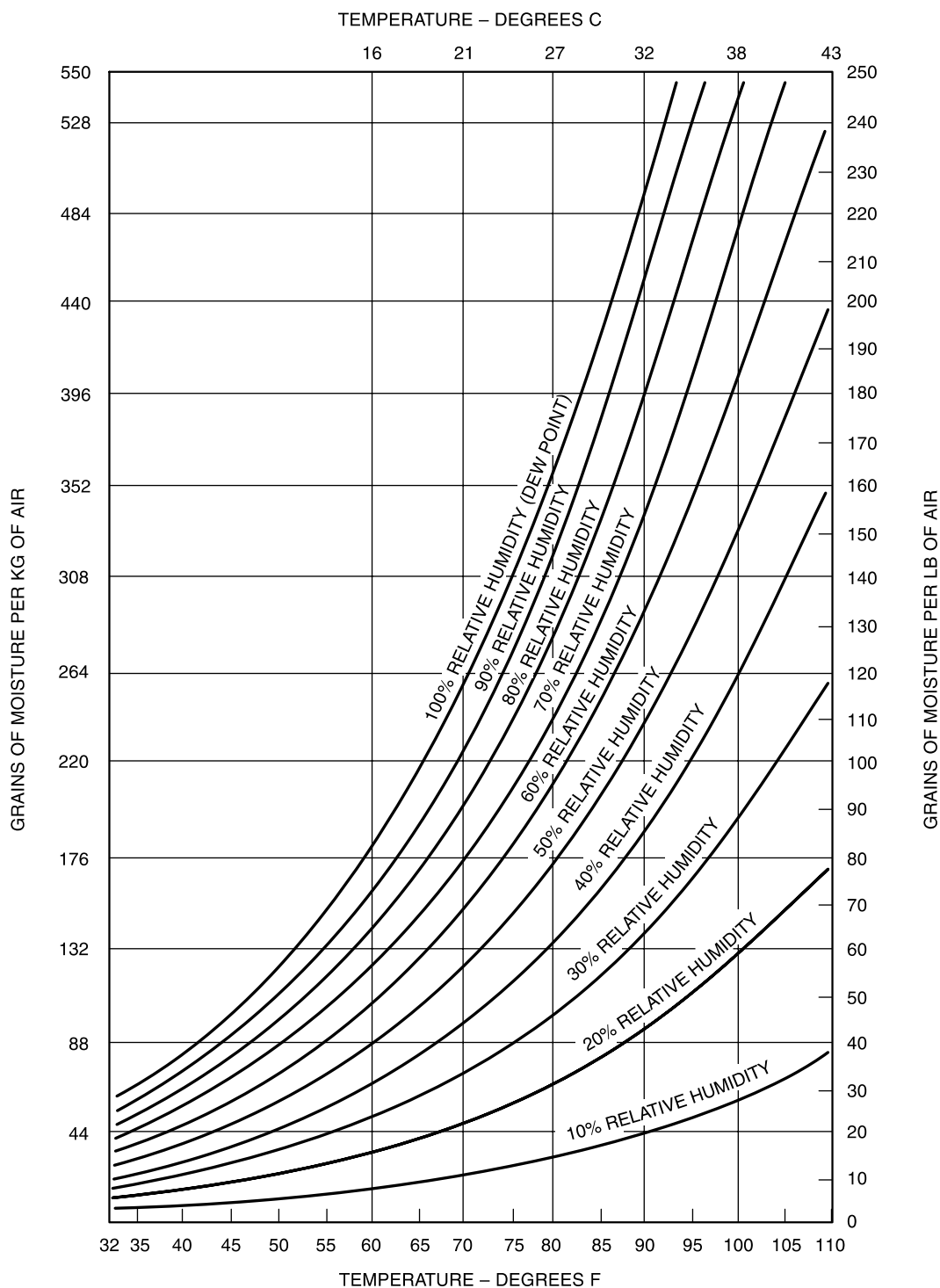
^a The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight per foot as the deformed bar.
^b The bar size number is based on the number of eighths of an inch in the nominal diameter of the bar.

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Annex C (Informative)

Temperature–Moisture Content Charts

This annex is not part of this standard but is included for informational purposes only.



Notes:

1. Any standard psychrometric chart may be used in lieu of this chart.
2. See Figure C.2 for an example of the application of this chart in establishing electrode exposure conditions.

Figure C.1—Temperature–Moisture Content Chart to be Used in Conjunction with Testing Program to Determine Extended Atmospheric Exposure Time of Low-Hydrogen Electrodes (see 7.9.3)

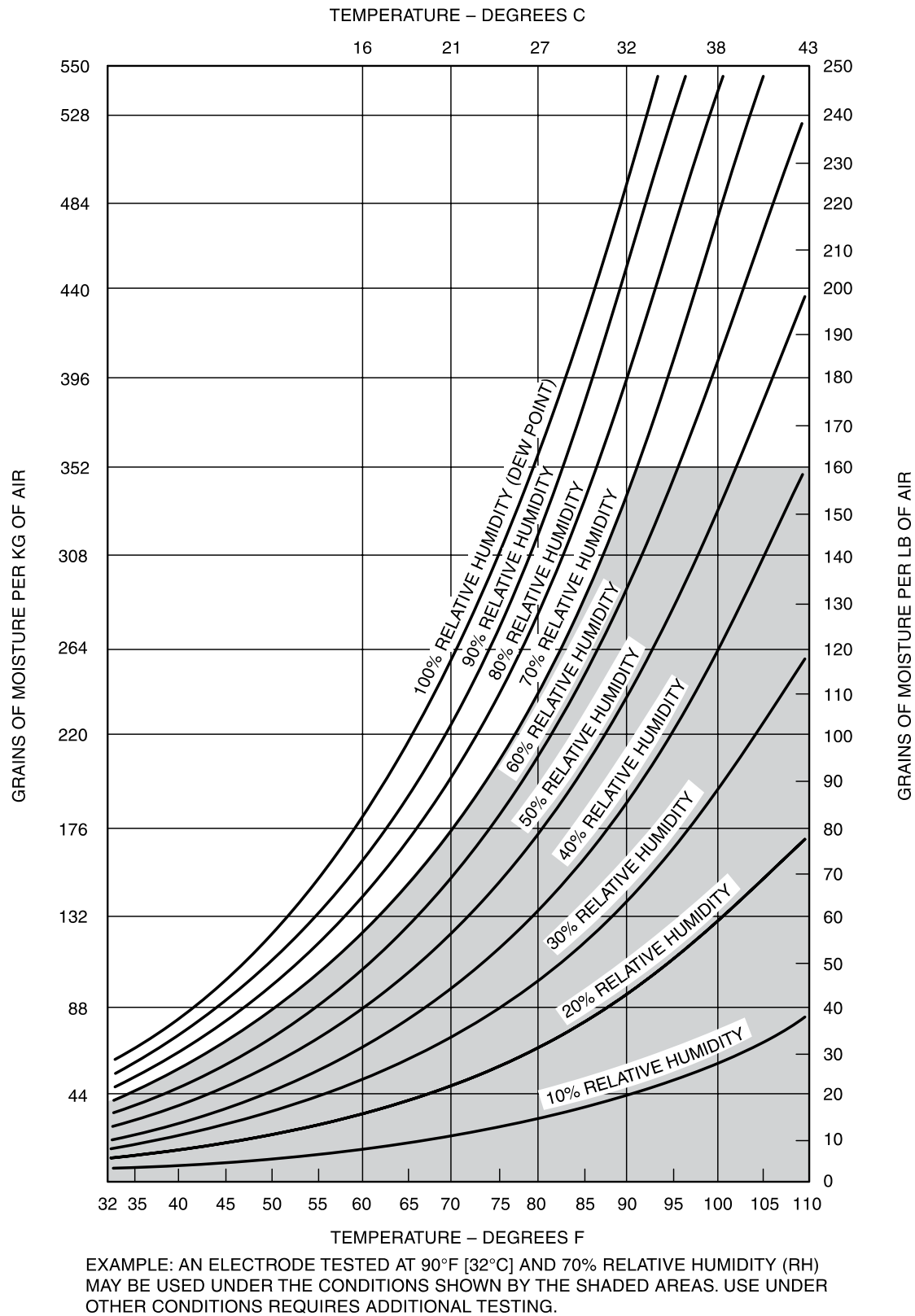


Figure C.2—Application of Temperature–Moisture Content Chart in Determining Atmospheric Exposure Time of Low-Hydrogen Electrodes (see 7.9.3)

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Annex D (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

D1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

D2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

D3. General Procedure for all Requests

D3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

D3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

D3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

D3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no.' The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

D3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

D3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

D4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

D5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

D6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

Commentary on **Structural Welding Code—** **Steel Reinforcing Bars**

8th Edition

Prepared by the
D1 Committee on Structural Welding

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

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Foreword

This foreword is not part of this standard but is included for informational purposes only.

This commentary on AWS D1.4/D1.4M:2018 is new and has been prepared to generate better understanding in the application of this code to welding with steel reinforcing bars.

As this code is written in the form of a specification, it cannot present background material or discuss the Structural Welding Committee's intent; it is the function of this commentary to fill this need.

Suggestions for application as well as clarification of code requirements are offered with specific emphasis on new or revised sections that may be less familiar to the user.

The nature of inquiries directed to the American Welding Society and the Structural Welding Committee has indicated that there are some requirements in this code that are either difficult to understand or not sufficiently specific, and others that appear to be overly conservative.

It should be recognized that the fundamental premise of this code is to provide general stipulations applicable to any situation and to leave sufficient latitude for the exercise of engineering judgment.

Another point to be recognized is that this code represents the collective experience of the committee and while some provisions may seem overly conservative, they have been based on sound engineering practice.

The committee, therefore, believes that a commentary is the most suitable means to provide clarification as well as proper interpretation of many of this code's requirements. Obviously, the size of the commentary had to impose some limitations with respect to the extent of coverage.

This commentary is not intended to provide a historical background of the development of this code, nor is it intended to provide a detailed resume of the studies and research data reviewed by the committee in formulating the provisions of this code.

The committee recommends that users of this code be guided by this commentary in application of this code to the welded structure. The commentary is not intended to supplement code requirements, but only to provide a useful document for interpretation and application of the code; none of its provisions are binding.

It is the intention of the Structural Welding Committee to revise the commentary on a regular basis so that commentary on changes to this code can be promptly supplied to the user. In this manner, the commentary will always be current with the edition of the *Structural Welding Code—Steel Reinforcing Bars* with which it is bound.

As this commentary is new to this code, all text is underlined.

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Commentary on Structural Welding Code—Steel Reinforcing Bars

C-6. Workmanship

C-6.1 Preparation of Base Metal

C-6.1.1 General. For quality welds, base metal cleanliness is important. However, it is neither required nor necessary for base metal to be perfectly clean before welds are made. It is difficult both to establish quantifiable limits of cleanliness and to measure to those limits; therefore, this provision uses the practical standard of the resultant weld quality. If the base metal is sufficiently clean so as to facilitate a weld to be made that meets the requirements of this code, it is clean enough. If the resultant welds do not meet the quality requirements of this code, cleaner base metal may be required.

C-6.1.2 Mill-Induced Surface Defects. The base metal to which welds are attached must be sufficiently sound so as to not affect the strength of the connection. Base metal defects may be repaired prior to the deposition of the prescribed weld. This subclause does not limit base metal repairs by welding. Defects that may be exposed on cut edges are governed by 6.1.2.

C-6.1.3 Scale and Rust. Excessive rust or scale can negatively affect weld quality. This code permits welding on surfaces that contain mill scale, providing both: (a) the mill scale remains intact after wire brushing and (b) the resultant weld quality is not adversely affected.

C-6.1.4 Foreign Materials. Surfaces contaminated by the materials listed in 6.1.4.1 must be cleaned, such as by wiping prior to welding. Special consideration should be given to the removal of surface contaminants containing hydrocarbons or condensed moisture, as the hydrogen released into the molten weld pool can cause serious weld imperfections, e.g., cracking. The cleaning operations, which may involve just wiping, need not remove all foreign contaminants nor do they require the use of solvents; welding through thin layers of remaining contaminants is acceptable, unless they degrade the quality requirements of this code resulting in unacceptable welds.

C-7. Technique

C-7.11 FCAW and Metal Cored Specification

AWS A5.36/A5.36M, *Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding*, is the first of combining carbon and low-alloy steel electrodes into one specification with fixed and open classification systems and with other specifications being considered in the A5 subcommittees. AWS A5.36/A5.36M has combined both carbon steel and low-alloy flux cored, and incorporated gas metal arc welding-metal core electrodes as well into the specification due to their tubular construction. The specification has two classification systems for carbon steel electrodes, fixed and open classifications for multi-pass electrodes, except the T11 FCAW and E70C-6C, E70C-3C, E70C-3M, and E70C-G GMAW-metal core are classified under open classification system. Low alloy FCAW and GMAW-metal core can only be classified by the open classification system.

When AWS A5.36/A5.36M is to be the governing specification for these FCAW and GMAW electrodes, existing contracts with fabricators may be used with the electrode specifications AWS A5.18/A5.18M, AWS A5.20/A5.20M, AWS A5.28/A5.28M, and AWS A5.29/A5.29M, as referenced in existing WPSs.

The AWS A5.36/A5.36M fixed and open classification of electrodes are intended to be identical or as similar as possible to the existing classifications of AWS A5.18/A5.18M, AWS A5.20/A5.20M, AWS A5.28/A5.28M, and AWS A5.29/A5.29M specifications in Table 5.1 for consistency with existing prequalified and qualified WPSs. In this way these prequalified and qualified WPS may be used with editing changes to reflect AWS A5.36/A5.36M.

In the case of the new AWS A5.36/A5.36M, *Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding*, filler metals with fixed and/or open classifications that are identical to the mechanical properties and chemical composition requirements of the previous specifications AWS A5.18/A5.18M, AWS A5.20/A5.20M, AWS A5.28/A5.28M, and AWS A5.29/A5.29M, and having the same shielding gas requirements for classification of these specifications are considered acceptable for existing valid WPSs. Editing of the prequalified and qualified WPS(s) with the new A5 specification and classification is the only change required for the WPS(s).

AWS A5.36/A5.36M does not identify any particular shielding gas for qualification of electrodes, except for the carbon steel fixed classifications. The AWS A5.36/A5.36M classification system uses shielding gas ranges for classification, however, the nominal shielding gas percentage of the range is the actual classification gas per Table 5 of AWS A5.36/A5.36M.

To provide continuity, the classification shielding gases identified in some of the electrode classifications in Table 7.1 are identical to the previous AWS A5.18/A5.18M, AWS A5.20/A5.20M, AWS A5.28/A5.28M, and AWS A5.29/A5.29M in order to maintain existing prequalified and qualified WPSs.

Other shielding gas(es) may be used for classification as indicated in Table 7.1 classifications, but for the purposes of the Code provisions, should be limited to the specific shielding gas or mixture used for classification, and not the range of the shielding gas designator of Table 5 of AWS A5.36/A5.36M.

Carbon steel FCAW T-12 classification under the AWS A5.20/A5.20M specification has a controlled chemical composition and mechanical properties. Under the new specification AWS A5.36/A5.36M, these requirements remain identical in the fixed classification, however, under the open classification the chemical composition requirement remains as in AWS A5.20/A5.20M, but the mechanical requirement range has been expanded to an upper tensile strength of 95 ksi [655 MPa], rather than the previous 90 ksi [620 MPa] of AWS A5.20/A5.20M or the fixed classification of AWS A5.36/A5.36M.

The “J” optional designator does not exist in AWS A5.36/A5.36M, and for those FCAW electrodes that were previously classified with the “J” designator, the open classification is required to classify an electrode with the lower CVN temperature requirement of a previous “J” designator.

In the open classification of electrodes, both carbon and low-alloy steel may be classified in the as-welded or postweld heat treated condition, or both. The letter “A” for as-welded or the letter “P” for postweld heat treated conditions is located in between the shielding gas designator, if applicable, and the CVN test temperature, examples E8XT1-C1A8-CS1; E7XT15-M21P6-CS2.

There are both subtle and major changes in AWS A5.36/A5.36M, too numerous to elaborate on in this commentary. Obtaining a copy of AWS A5.36/A5.36M by engineers and fabricators for their reference is highly advisable.

C-9. Inspection

C-9.9.1 Radiographic Testing of Direct Butt Joints

Procedures and Standards. The procedures and standards set forth in this code are to govern the radiographic testing of welds when such inspection is required by the contract documents as provided in 9.9.2. The requirements listed herein are specifically for testing groove welds in direct butt joints in steel reinforcing bars by X-ray or gamma-ray sources.

NOTE: Inspection of flare-V- and flare-bevel-groove welds or fillet welds by radiographic testing method is, in general, not considered feasible, except by highly specialized techniques, and is not recommended.

Variations. Variations in testing procedures, equipment, and acceptance standards may be used with approval of the Engineer. Such variations include, but are not limited to, the following: Changes in source-to-film distance; unusual application of film; unusual hole-type image quality indicators (IQI) applications (including film side IQI); film types, densities, and variations in exposure, development, and viewing techniques.

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List of AWS Documents on Structural Welding

Designation	Title
A2.4	<i>Standard Symbols for Welding, Brazing, and Nondestructive Examination</i>
A3.0M/A3.0	<i>Standard Welding Terms and Definitions, Including Terms for Welding, Brazing, and Nondestructive Examination, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying</i>
D1.1/D1.1M	<i>Structural Welding Code—Steel</i>
D1.2/D1.2M	<i>Structural Welding Code—Aluminum</i>
D1.3/D1.3M	<i>Structural Welding Code—Sheet Steel</i>
D1.4/D1.4M	<i>Structural Welding Code—Steel Reinforcing Bars</i>
D1.5/D1.5M	<i>Bridge Welding Code</i>
D1.6/D1.6M	<i>Structural Welding Code—Stainless Steel</i>
D1.7/D1.7M	<i>Guide for Strengthening and Repairing Existing Structures</i>
D1.8/D1.8M	<i>Structural Welding Code—Seismic Supplement</i>
D1.9/D1.9M	<i>Structural Welding Code—Titanium</i>

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